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16. ABSTRACT

This is the Final Technical Report of the Black Creek sediment control project. This project is to determine the environmental impact of land use on water quality and has completed its four and one half years of watershed activity. The project, which is directed by the Allen County Soil and Water Conservation District, is an attempt to determine the role that agricultural pollutants play in the degradation of water quality in the Maumee River Basin and ultimately in Lake Erie.

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ENVIRONMENTAL IMPACT OF LAND USE ON WATER QUALITY

Final Report on the Black Creek Project (Technical Report)

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UNDER U.S. EPA GRANT NO. G005103

to

ALLEN COUNTY SOIL & WATER CONSERVATION DISTRICT

U.S. Department of Agriculture, SCS, ARS
Purdue University, University of Illinois

1a

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1.1 HISTORY

The problem of nonpoint source pollution of the nation's streams and lakes has become a subject of increased attention because of the requirements of Section 208 of Public Law 92-500 for water quality management planning.

Prior to the final passage of this act, the question of "agricultural pollution" had been discussed in depth during a one-day conference on the Maumee River held in Fort Wayne, Ind. in early January of 1972. This conference, sponsored by Rep. J. Edward Roush (Ind.-4), provided one of the first public discussions of the nonpoint source pollution problem in northeastern Indiana and the Maumee River Basin.

As a result of the Maumee River Conference, local, state and federal officials, representatives of agricultural and environmental protection groups, and other interested citizens undertook a series of discussions of the problems of erosion and sediment related pollution of the Maumee River and ultimately Lake Erie. These discussions were arranged by the Allen County Surveyor, William Sweet, and by then State Conservationist Thomas Evans of the Soil Conservation Service, USDA.

As the result of these discussions, a proposal to study the problems of agricultural pollution of the Maumee River was developed by the Allen County Soil and Water Conservation District.

The proposal called for the cooperation of the District, Purdue University and SCS in a demonstration project, supported by research. This proposal, entitled "A Proposal for the Reduction of Sediment and Related Pollutants in the Maumee River and Lake Erie," was submitted to Region Five of the Environmental Protection Agency in June of 1972.

The proposal was assigned to the Office of Great Lakes Coordinator where funding was available under Section 15 of the water quality amendments of 1970. Section 15 became Section 108(a) with the adoption of the 1972 amendments. The Section 108 program, administered from the Region V EPA office, is a special program created by Congress to demonstrate means of improving water quality within the Great Lakes Basin. The act calls for federal participation of 75 percent of the total cost for demonstration projects. Research is funded under the program in support of the demonstration effort.

In October of 1972, almost simultaneously with the adoption of Public Law 92-500, a six-month planning grant was awarded to the Allen County Soil and Water Conservation District to design, in detail, the demonstration effort and related research.

This work was completed and is reported in Environmental Impact of Land Use on Water Quality -- A Work Plan. Some of the descriptive material about the area chosen for the study and its relation to the Maumee Basin and to Lake Erie is reported in this volume.

This document constitutes the final technical report on the five years of effort, beginning with the awarding of the planning grant and ending with the close of the project, Oct. 16, 1977. It is one of four volumes designed to provide a complete description of the work accomplished and the results obtained during the course of the project. Other volumes include a non-technical summary volume, a data volume in which information collected during the project is summarized, and a volume made up of papers prepared by individual researchers and administrators who worked on the project.

Section 1.2 lists a large number of individuals and organizations who have been associated with the Black Creek project. Some observations about the success with which this diverse group has operated and the ability of this project to relate to individual landowners within the project area are in order.

It is important to observe that the Black Creek project was developed by interested persons in the local community and was not imposed from outside. The specific sequence of events was as follows:

(1) A problem was identified by speakers participating in an open public meeting (the Maumee Conference).
(2) Interested governmental officials and private citizens discussed the problem in a neutral forum. At this point, there was no implied pressure to take any specific action, although a realization that a problem as serious as this one had been described was likely to produce governmental action was present.
(3) Funding to attack the problem was made available by EPA.
(4) A program satisfying diverse interests was proposed.
(5) Funding was made available for a detailed plan for a program which involved local control through the sponsorship of the Soil and Water Conservation District.
(6) The program was funded and has been carried out.

Particular attention was paid to the need for keeping the general public and affected landowners involved in the project. The Maumee Conference was a public meeting. Although discussions at the Sweet-Evans meetings were not extensively covered in the local press, they were not closed meetings, and all interested citizens were allowed to attend.

The processes of proposal submission, revision, and final acceptance was reported in the press. In addition, special meetings were held with affected landowners, and contact was maintained by face-to-face communication and by letter.

As a result, rumors and hostilities that could have developed were largely avoided. At the close of the project, both environmental and agricultural interests remained supportive of the concept and the project.

Early in the conduct of the project, it was decided to hold monthly "steering committee" meetings during which representatives of involved agencies would be present. These meetings included both administrative and research personnel. Minutes were prepared and distributed. Discussion was open and covered all aspects of the project. As a result, communication among researchers and communication between administrators and researchers was excellent, and the project had a better focus than might otherwise have been the case.

1.2 PROGRAM PARTICIPANTS

The success of the Black Creek project has depended on several key elements. Most important has been the coordination of the efforts of diverse administrative and technical interests in the project. Primarily, agencies involved included the Environmental Protection Agency, which provided funding, the Allen County Soil and Water Conservation District, which assumed overall responsibility for the project, the Soil Conservation Service of USDA, which provided technical assistance, Purdue University and the University of Illinois, which provided research support, and units of local and state government, which provided needed assistance.

Key personnel from these agencies are listed in the following discussion:

1.2.1 Environmental Protection Agency

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Carl Wilson, project officer, nonpoint source coordinator, Planning Branch, Region V EPA.

1.2.2 Allen County SWCD

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Members of the Board of Supervisors -- Ellis MacFadden, Roger Ehle, Mic Lomont, Eric Kuhne, John Hilger, Ray Arnold, Gilbert Whitsel.
Assistant Supervisor -- Don Rekeweg.
Employees of the Board of Supervisors:
James Lake -- project director
Dan Dudley -- aquatic biologist
Rex Journay -- tillage research
John Pidlisny -- technician
Alan Shupe -- technician

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John Dennison -- area technician
C. F. Polland -- area engineer
Planners and technicians -- Greg Woods, Gary Carlile, Doene Goettl, Bill Howard, Stan Steury, Darrell Brown.
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1.3 CONCEPT OF THE PROJECT

The Black Creek project has been misinterpreted by some observers as an attempt to have a direct, measurable impact on water quality in the Maumee River and Lake Erie. This goal, while a worthy one, has never been the aim of the Black Creek project. In fact, it is doubtful that any measurable impact on water quality in the river and the lake could be obtained if all of the runoff water from the 12,038-acre Black Creek area were diverted from the system.

Instead, the basic concept of the Black Creek project has been as a model. In fact, the Black Creek Watershed is similar to 200 to 300 agricultural watersheds in the Maumee Basin. The question has been whether techniques demonstrated in this watershed, if applied on a basin-wide basis, would likely improve the quality of water in the Maumee River and Lake Erie.

There have been two major thrusts simultaneously underway in the watershed. The first has been the demonstration effort itself, a project designed to demonstrate the effectiveness of traditional and innovative soil and water conservation techniques for improving water quality. The second has been the research effort, directed at understanding the mechanisms whereby the demonstrated techniques succeed or fail.

Initial project goals stated that it was desirable to know if a concentrated application of existing methods of land treatment in the Maumee Basin could achieve a desired reduction in sediment. It was also desired to estimate how much such a program would cost on a basin-wide basis.

Concurrently, the project was designed to discover what kind of program might be carried out on a basin-wide basis which would convince individual landowners to apply conservation practices for the improvement of water quality. Specifically, it was asked whether this can be adequately done on an incentive basis or whether some type of mandatory control of pollution from nonpoint sources might be imposed with a reasonable chance of success.

The purpose of the research conducted in conjunction with the demonstration project was to more fully understand the mechanisms whereby the demonstration project could reduce the sediment load entering the Maumee River and to utilize this understanding to project to the Maumee Basin an accurate estimate of methods that can be employed to achieve a desired improvement in water quality and the costs of doing so.

Robert Schneider, EPA Great Lakes Coordinator summarized EPA's interest in the Black Creek Project in light of additional developments over the past five years, in a meeting at Fort Wayne, Ind. Oct. 26, 1977. His remarks included the following observations:

"When the Environmental Protection Agency first authorized the project back in May of 1973, the Agency was seeking guidance for the nonpoint source pollution control program specifically as it relates to water quality. Under the provisions of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), the United States Environmental Protection Agency was given the primary responsibility for carrying out the Federal role in water pollution control under section 208 of this Act. Nonpoint source pollution control requires the development and implementation of area-wide waste treatment management plans that include procedures to reduce pollution from nonpoint sources.

"We are acutely aware that this requirement introduces a new aspect to our nation's pollution control efforts. Historically, pollution control efforts have concentrated on collection and treatment of wastes that are discharged from point sources. Nonpoint sources of pollution are not amenable to traditional methods of collection and treatment. Thus the approach recommended is prevention of pollution before it occurs, EPA has gone on record as advocating "Best Management Practices." The Black Creek Project has the opportunity to answer this challenge.

"What was not anticipated, as the Black Creek Project progressed, was a General Accounting Office report on Agricultural programs. I would like to quote part of this report to you:

> `If the United States is to continue to meet its own food needs and help alleviate world food shortages, it must maintain its top soil. Estimates of soil losses for 283 farms GAO visited on a random basis in the Great Plains Corn Belt, and Pacific Northwest, indicate that topsoil losses are threatening continued crop productivity.
>
> `Soil scientists estimate that annual soil losses must be limited to no more than 5 tons per acre in deep soils and one ton per acre in shallow soils to maintain soil fertility and productivity over time. According to Department of Agriculture technicians, about 84 percent of the 283 farms were losing over five tons per acre per year on cropland for which calculations were made. In addition, soil erosion was creating water and air pollution and highway maintenance problems.
>
> `Agriculture's Soil Conservation Service and Agricultural Stabilization and Conservation Service administers technical and financial assistance programs -- costing several hundred million dollars annually -- designed to help farmers control erosion and preserve topsoil.
>
> `These programs have not been as effective as they could be in establishing enduring soil conservation practices and reducing erosion to tolerable levels.'

"We in Environmental Protection Agency hope the Black Creek Project results will help to resolve the issues in the General Accounting Office report to Congress. To this end, let me state some of the major EPA expectations from the Black Creek Project:

"1. That the study will develop `Best Management Practices.'

"2. That from a given set of practices, a specific level of water quality can be expected.

"3. That a model institutional mechanism to implement a nonpoint source program will be developed.

"4. That successful projects will be clearly identified and that the ones that have failed will be similarly identified.

"5. That economic data will be developed that evaluates best management practices in reference to water quality.

"6. That the social impacts from the study will be clearly identified.

"7. That best management practices will be developed so as to have a beneficial effect on the biological system of a stream.

"8. That guidelines for cost sharing will be developed.

"These, then, are the highlights of EPA's expectations from this project. I suggest that in the discussions over these two days, you give considerations to these expectations, and any others you believe merit attention."

References

1. Environmental Impact of Land Use on Water Quality -- A Work Plan; EPA Region V, 1973.

2. General Accounting Office, To Protect Tomorrow's Food Supply, Soil Conservation Needs Priority Attention; 1977.

3 Schneider, Robert, "EPA Expectations of Black Creek" speech, Fort Wayne, Indiana, 1977.

CONCLUSIONS

II. CONCLUSIONS

The Black Creek demonstration and research project led to several general conclusions which are reported in this section. Additionally, more specific conclusions are included in the various sections of this document. The conclusions reported in this section represent a consensus of the investigators and administrators in the Black Creek project. The order in which they are presented is not intended to reflect the degree of importance with which the conclusion or subject is viewed.

2.1 FECAL POLLUTION OF BLACK CREEK

(See Section 4.4)

Fecal contamination and water quality criteria have significant implications for the swimmable fishable goal of public law 92-500. If that goal is defined to mean water clean enough to allow whole body contact recreation, then fecal coliforms should not exceed 200 per 100 ml. This value represents a threshold value above which the frequency of water borne human pathogens greatly increases. Under current regulations for the Maumee River and Black Creek, the standard is a weighted average of no more than 1,000 fecal coliforms per 100 ml, and a peak value of no more than 2,000 per 100 ml. These standards, in effect, regulate the water quality at a level which insures only limited body contact recreation, such as fishing and boating.

1. Fecal coliforms for the Black Creek in general exceed the water quality standards for whole body contact (200 per 100 ml).

2. Fecal coliform concentrations were not demonstrated to surpass the existing Maumee River standard in the portions of Black Creek not influenced by discharges (septic tank effluent) from the town of Harlan (pop. 600). However, these standards were exceeded in portions of Black Creek influenced by the town of Harlan.

3. Livestock sources of fecal pollution were detected during a runoff event in March, 1977, in areas with unconfined livestock operations (pasture and barnlot).

4. High flows carried higher concentrations of bacteria than low flows as a result of two phenomena:

   (1) contamination from human sources is flushed from fecally contaminated bottom sediment in channels and/or tile lines during high flows, and

   (2) contamination from livestock sources is carried by surface flow to stream channels.

5. Biotic communities of stream reaches below septic tank outfalls and below livestock waste discharges were affected in the following ways:

   (1) Only the most pollution tolerant forms are present in areas of long-term, gross pollution (at septic tank outfalls).

(2) Modified invertebrate species composition and abundances are recorded in areas of long-term, moderate to low levels of pollution downstream of septic tank outfalls.

(3) The effect on aquatic life of short-term, moderate to high levels of pollution during some runoff events has not been established.

(4) Short-term, gross pollution caused by a discharge of manure slurry from an animal waste holding pit resulted in an extensive fish kill (8 km of stream) and a complete disruption of the aquatic community.

6. In the vicinity of septic tank outfalls, aquatic communities are adversely affected.

2.2 TOXIC SUBSTANCES

(See Section 4.4.8)

1. Spot checks of levels of contamination by a variety of toxic substances (pesticides, PCB's, and heavy metals) in water, sediment, and fish tissue show these to be at levels below those of concern for human health.

2.3 FISH

(See Section 4.5)

1. Thirty-five species of fish have been collected in the Black Creek watershed. However, this number of species does not necessarily reflect the decline in value of the fishery resource in Black Creek.

2. Many individuals and some species migrate into the Black Creek watershed each year in search of spawning and nursery grounds.

3. Others reside permanently in the watershed, especially in more protected areas associated with forested sections of streams.

4. Fishes in unprotected areas tend to suffer high mortality and depend on replacement from outside areas each year. Unprotected areas include regions of straight stream channels and areas not shaded by overhanging vegetation. Typically they will also have uniform bottoms, often of sand or silt.

5. Even relatively protected areas, such as wooded streams, will experience massive mortality in unusually dry or cold periods.

6. In Black Creek all areas are recolonized quickly (during the next spring), even after mass mortality, unless channels are obstructed by construction or other activities. Other activities include channel modification which create unsuitable habitat -- high temperatures, low oxygen content, algal blooms, etc. However, the recolonization is often futile because the fishes will soon die in the poor habitat of unprotected areas.

7. The primary factor governing diversity of fish communities is complexi-

ty of habitat. More diverse habitat structure will support fish communities of high diversity.

8. These results show that it will take more than improved water quality to insure that waters are "fishable." Management for "fishable and swimmable" objective must also consider suitable habitat structure, trophic structure of community, allocthonous energy inputs, and temperature regimes.

2.4 CONSERVATION PRACTICE INSTALLATION AND WATER QUALITY

(See Section 4.15 and Section 5.3)

The project work plan did not call for detailed study of construction impacts on water quality. It is generally agreed that erosion is greatly accelerated by construction activities including the installation of many permanent practices. (For example, stream bank protection, structures, grassed waterways and PTO terraces.) The following fundamental points concerning construction and water quality need to be stressed because they were overlooked in the planning of Black Creek.

1. Construction activities associated with the installation of conservation measures can result in short term concentrated delivery of sediment to stream channels and the alteration of biotic communities. Depending on the magnitude of the construction, on-site and downstream water quality, stream habitat, and biotic communities are altered for time periods of several days up to several years.

2. Streams with aquatic resource potential need to be identified and protected from construction induced damages.

3. Programs that utilize soil conservation practices to improve water quality demand careful planning and installation of the practices to reduce sediment delivery to streams and other associated impacts on downstream and on-site aquatic resources.

4. Planners and field technicians need to be trained in the ecological principles that are the basis of understanding and recognizing sensitive aquatic resources.

2.5 NUTRIENT AND SEDIMENT TRANSPORT

(See Section 4.6, Section 5.2, and Section 5.3)

1. Amounts of runoff, sediment, and nutrients discharged from a small watershed are greatly affected by rainfall. Reductions in rainfall give a greater percentage reduction in runoff which in turn gives a still greater percentage reduction in sediment and nutrient transport.

2. During years with above average rainfall, land slope is clearly the dominant factor affecting sediment yields. However, with below average rainfall, the effect of land use on sediment yields becomes relatively more important. This reflects the natural sequence of the rainfall-runoff event

because rainfall must first meet the storage capabilities of the soil and land surface before runoff begins.

3. With average or above average rainfall patterns, more than 90 percent of the total phosphorus transported is sediment bound, while only about 50 percent of the total nitrogen transported is sediment bound. Models of P transport can be based on the erosion sedimentation process. We recommend that models of N transport not be based on the erosion-sedimentation process only.

4. Transport of sediment and nutrients is strongly associated with large storms which occur only a few times during a year.

5. In order to characterize nutrient and sediment loading from small watersheds, runoff from large storm events must be well-monitored and, with few exceptions, automated sampling is required.

6. During snow melt, the transport of soluble nutrients may be disproportionally high when compared with snow melt runoff.

7. Sediment and sediment-associated nutrient concentrations increase markedly with large storm events.

8. Average concentrations of sediment and nutrients discharged from the Black Creek Watershed are in line with measured concentrations in the Maumee River.

9. Losses of soluble inorganic phosphorus, ammonium and nitrate-nitrogen from the watershed are partially due to the input of these chemical forms by precipitation.

10. Most of the sediment and sediment-bound nutrients originate in runoff from the land surface. The discharge of ammonium is also largely associated with runoff from land surfaces. However, the discharge from septic tank outlets contributes substantial amounts of soluble inorganic phosphorus into the streams in the watershed.

11. Sediments in runoff are nutrient enriched. The least enrichment occurs from subsurface drains and the most from septic tank outfalls. The sediments in Black Creek have an enrichment factor of about three as compared to the uneroded soils in the watershed.

12. Farming techniques common to the 19th century but still used by the Amish did not seem to improve the water quality in streams from that area of the Black Creek Watershed in which they reside.

13. The effects of agricultural nonpoint source pollution and point source pollution on our water resources are sufficiently different that direct comparisons between them cannot be made and separate objectives for their evaluation and control are in order.

14. In the absence of surface runoff and tile flow, quality of ground water flowing in channels downstream changes, demonstrating that stream channel and riparian environments affect water quality.

15. During most flow conditions, large inputs of sediment and nutrients

occur at Harlan.

16. Areas remote from Harlan generally have lower nutrient and sediment concentrations than those at Harlan.

17. Water quality characteristic vary significantly over short stream distances. This emphasizes the importance of careful selection of monitoring stations for monitoring water quality.

18. A meandering section of stream flowing through a woodlot acted like a natural sediment trap.

19. Adjacent subwatersheds of similar size, topography and soil type produce runoff of varying quality due to differences in land use and application of conservation practices. These results emphasize the need for detailed experimental analysis of the determinants of water quality.

2.6 STREAM CHANNEL STABILITY

(See Section 4.2)

1. Total stream bank erosion is small although at the site of erosion it may appear severe. There is no apparent correlation of bank erosion with adjacent land use. Over 80 percent of the bank erosion was reported in the areas containing Eel and Shoals type soils.

2. Channel bottom erosion produced unstable channel banks in several areas. Channel stabilizing structures and bank stabilizing activities have eliminated many severe problems. Rock drop structures were especially successful for this purpose.

3. Seeding of the banks to establish vegetative cover is most successful where slopes are 2:1 or flatter. The advantage of the flatter slopes justify the additional land area required to install them. Mulch is necessary to establish a good seeding. Stone mulch materials are the most successful. The stone mulch has the advantage of not being washed away during periods of high flow.

2.7 SEDIMENT POND

(See Section 4.3)

1. The sediment pond had a measurable and beneficial impact on water quality. However, it is recognized that, in the long term, a pond which removes a large quantity of sediment will require either a difficult cleanout or will become ineffective.

2. In the first two years following construction of the sediment pond an equivalent amount of sediment to 2.8 t/ha/yr (1.2 T/ac/yr) from the entire watershed was collected in the pond. Most of this was due to one 50-year recurrence interval storm which caused unusual erosion on the nearly level watershed.

3. No measurable increase in sediment was observed from July 1976 through

July 1977. During this period, runoff was small and very little erosion was occurring on the watershed.

4. About 95 percent of the material reported above was particles less than 50 μm in diameter. This indicates the effectiveness of the pond in trapping particles which control are difficult to control by land treatment consistent with row crop production and suggests the value of sediment ponds.

2.8 IN CHANNEL DESILTING BASIN

(See Section 4.3)

1. During the first two years following construction, the basin was approximately one-half filled due in part to channel construction activities above the basin and to one greater than 50-year recurrence interval storm.

2. The largest amount of material was of the coarser particles.

3. Turbidity, total solids, and total phosphorus increase as the water transits the basin during low flow conditions.

4. For continued operation, periodic clean out would be required.

5. Except in unusual circumstances, the use of an in-channel desilting basin will have negative impacts on water quality and is not recommended.

2. 9 TILLAGE

(See Section 4.7)

1. On soils where conservation tillage for corn is adapted and where pests are easily controlled, there should be little or no cost for the benefits gained in erosion control and water quality.

2. Fall chiseling can replace moldboard plowing for corn after corn or corn after beans, on most Black Creek soils without limiting production, where weeds can be controlled.

3. Shallow tillage or no-till planting for corn after corn or corn after beans should not limit production on well or moderately well drained soils where perennial weeds are not a serious problem.

4. No-till planting for corn into a chemically killed sod should not limit production, compared to moldboard plowing, where perennial weeds are not a serious problem.

5. Perennial and herbicide resistant weeds, such as Canada thistle, field bindweed and morning glory are more likely to be yield limiting factors for soybeans than for corn with no-plow tillage.

6. Shallow tillage or no-till planting, is likely to lead to more serious phytophthora root rot problems for soybeans on poorly drained soils, unless

resistant varieties are available.

7. Farmers are not likely to adopt conservation tillage practices until success can be proven and demonstrated in their area.

8. Some form or forms of conservation tillage that have proven to be adapted to soils in an area should be a high priority BMP.

9. For corn, where perennial and resistant weeds are a problem, added herbicide costs and/or reduced yields with conservation tillage will reduce profit. With herbicides currently available, the effect of problem weeds on soybeans under conservation tillage is likely to be more severe than on corn.

2.10 TILE DRAINAGE

(Based on Grab Samples)

(See Section 4.6)

1. Tile effluent yields small amounts of sediment and sediment-bound nutrients.

2. Tile effluent is relatively high in nitrate-N concentrations as compared to these concentrations in the receiving streams.

3. Nitrate concentration in tile effluent increased with intensity of row crop farming.

4. Septic contamination of tile outlets is common and greatly increases the soluble inorganic phosphorus and ammonium yields from the Black Creek Watershed .

5. Sediment and nutrient concentrations are not correlated with tile flow for most of the tiles monitored.

6. Tile discharge must be well monitored during storm events to get meaningful loading data. Data from grab samples are not sufficient to determine storm induced loadings.

7. The low degree of correlation emphasizes the inherent weakness with any weekly grab sampling program especially for small watersheds.

(Based on Automatic Sampler)

(See Section 4.6)

1. BMP's which allow more water to flow through a tile drainage system will significantly reduce total losses of runoff,sediment and nutrients. Nitrate-N is the only nutrient which may increase in concentration, but the

greater percentage reduction in runoff yields a lower total loss.

2. Rainfall during late winter and early spring produces a high percentage of the annual water, sediment and nutrient loses from an agricultural tile drainage system.

3. A positive correlation (R-squared = 0.1 to 0.86) is shown between sediment and nutrient concentrations and tile flow.

4. Initial flow following a storm yields higher sediment and nutrient concentration levels than equivalent flow levels when discharge is receding.

5. The monitored Hoytville soil is very responsive hydrologically to subsurface drainage and appears to have a higher hydraulic conductivity than indicated in published soil survey reports. This may be due in part by deep cracking of the soil.

6. Tile flow exhibits a diurnal variation during freeze-thaw periods of the year.

7. Tile effluent yields an insignificant amount of phosphorus to streams as compared to surface runoff.

8. Nitrate is the dominant nutrient in tile effluent. Losses of total nitrogen were on the order of 5 percent of nitrogen applied as fertilizer for two rather dry years.

9. Both insecticide and herbicide were detected in the tile effluent shortly after a surface application. Losses were of the order of .1 percent of applied amounts. Deep cracking is believed to be the reason for this pesticide movement.

2.11 WATER QUALITY BASED ON GRAB SAMPLE DATA

(See Section 4.6.5)

1. Annual loadings were not accurately predicted by use of weekly grab samples alone (see Table 60). Weekly grab sampling provides adequate description only of base flow conditions .

2. For accurate loading information during storm events, grab sampling must be accomplished at an interval significantly shorter than the time response of a watershed.

3. An annual cycle exists for the concentration level of nitrate and to a much less degree for ammonia. Suspended solid and phosphorus data did not exhibit this behavior.

4. Total phosphorus and nitrogen concentrations have a positive correlation (R-squared = 0.11 to 0.60) with suspended solids concentrations, whereas soluble forms of phosphorus and nitrogen are not correlated with suspended solids (see Table 61).

5. Suspended solid and sediment bound nutrient concentrations have a positive correlation (R-squared = 0.092 to 0.41) with stage. Soluble com-

ponents have no correlation with stage.

6. Water quality data for streams from small watersheds exhibits a high degree of scatter, due in part to the wide variation in flow.

7. There is no simple function relationship between flow rate and suspended solid or nutrient concentrations.

2.12 ALGAL BIOASSAY STUDY

(See Section 4.11)

1. Maximum algal growth occurred at soluble P levels of approximately 0.1 mg/l.

2. Not all soluble P in Black Creek drainage water was available to algae in a four day incubation.

3. Phosphorus was the major limiting nutrient for algal growth in Black Creek drainage water.

4. Addition of micronutrients increased algal growth and apparent P availability to algae suggesting that the micronutrient content of water limits algal growth in sediment-free systems.

5. Approximately 20 percent of total sediment-bound P was available to algae in a two week incubation. Samples taken in March and June yielded similar results.

6. Approximately 30 percent of sediment-bound inorganic P was available to algae in a two week incubation.

7. The ammonium flouride, sodium hydroxide, and HCl extractable fractions of sediment inorganic P all contribute to the pool of available P for algae. The ammonium flouride and sodium hydroxide extractable sediment inorganic P fractions were the most available to algae representing an average of 43 and 38 percent of P taken up respectively.

2.13 LABORATORY INCUBATION STUDIES

(See Section 4.10)

1. The concentration of nitrate N in incubated Black Creek stream samples increased with time as a result of mineralization and nitrification. Treatments which increased microbial growth (high temperatures, aeration, calcium carbonate amendment, and addition of inorganic N) increased the rate of mineralization in samples.

2. The concentration of soluble inorganic P in incubated Black Creek stream samples slowly increased with time. Increased temperatures and aeration accelerated release of soluble inorganic P from sediment.

2.14 RAINULATOR

(See Section 4.1)

1. Soil losses from nearly level lake plain soils under fallow conditions are much less than those of more sloping soils in the watershed. Even on nearly level soils, significant differences in loss can occur. These are related to soil structure.

2. Soil erosion is a highly selective process. Sediment shows distinct clay enrichment and sometimes silt enrichment.

3. Effective measures for reducing erosion on nearly level soils should be based on prevention of detachment of naturally occurring aggregates.

4. Protecting the soil surface from raindrop impact is one of the most effective means of minimizing sediment concentrations in runoff.

5. Soil losses are reduced by those tillage systems which leave appreciable crop residues on the surface.

6. Fall chiseling after corn, although not as effective as the no-til and disc treatments, significantly reduces erosion compared to moldboard plowing.

7. None of the conservation treatments are as effective following soybeans as following corn.

8. Sediment loads can be reduced by sod buffer strips. The effectiveness of this practice is dependent on composition of sediment; rate and depth of flow; and vigor and height of sod.

9. Incorporation of applied annual waste will reduce nutrient losses in runoff.

10. Waste application tends to reduce soil loss because of mulch effect.

11. Sediments eroded from animal waste treated areas is highly enriched with nutrients because of manure particles in transported solids.

12. Waste application to untilled soil gave larger nutrient losses in runoff than waste application on areas receiving some fall tillage.

13. Surface applications of commercial fertilizers to fallow soils increase the concentration of soluble nitrate N, ammonium N, and soluble inorganic P in runoff. However, the portion of added fertilizer lost with intense rainstorms was low (less than 8% of added nutrients).

14. The majority of N and P in surface runoff from fertilizer cropland is transported eroded sediment. The bulk of sediment-bound N and P is associated with the clay fraction.

15. The most successful approach for minimizing nutrient losses in surface runoff from cropland is a combination of soil erosion control and incorporation of fertilizers after application.

16. For the purpose of modeling agriculture systems, certain parameters of surface runoff can be successfully estimated by analysis of the properties of sediments or surface soils.

a. The concentration of soluble inorganic P in surface runoff can be estimated by measurement of the equilibrium phosphorus concentration or the extractable phosphorus content of either the eroded sediment or original soil.

b. The concentration of soluble ammonium in runoff can be estimated from the exchangeable ammonium content of the eroded soil and original soil.

c. The concentration of nitrate in surface runoff was not related to any runoff properties measured. Modelling of nitrate loss in runoff will be difficult because nitrate losses are dependent upon a large number of factors.

2.15 WATERSHED MODEL

(See Section 4.9.1)

1. A comprehensive, distributed parameter simulator, named ANSWERS, has been developed.

2. ANSWERS offers unique and important capabilities for use during implementation phases of 208 planning.

3. The importance of applying non-point source control measures on a highly site-specific basis has been clearly demonstrated by use of the ANSWERS model on the Black Creek Watershed.

2.16 REMOTE DATA ACQUISITION

(See Section 3.4.3.1)

1. The feasibility has been demonstrated of operating a real-time environmental data acquisition system which supports remote field transducers and computer activated sampling equipment under control of a general purpose time-sharing system.

2. The concepts of the ALERT data acquisition system are applicable to numerous non-point source monitoring requirements and result in several operational benefits including: expanded data gathering, improved validity of field data, more efficient utilization of field personnel and automated early warning systems.

2.17 SOCIO-ECONOMIC CONCLUSIONS

(See Section 4.8)

1. Government agencies make an important contribution in encouraging the adoption of conservation practices by providing information to farmers about the practices.

2. The favorable attitude of farmers and the high level of participation indicate adoption of practices can be achieved in most cases without coer-

cive legislation.

3. A given level of water quality can be provided at the least cost to participating farmers when they are provided as many alternatives as possible in selecting the management practices to achieve that required level of quality.

4. Most economic costs are borne by those farmers who operate on the more erosive land. Therefore, it may be appropriate to concentrate the cost sharing assistance on these situations.

5. If the cost of a conservation practice is based only on yield reductions, the yearly dollar loss is dependent on crop pieces. When crop prices are low, the cost of reducing soil loss is significantly lower than occurs in periods of high farm product prices.

2.18 LAND MANAGEMENT

(See Section 3.3 and Section 5.1)

1. The traditional approach to planning each acre is too methodical to meet water quality objectives set out in 208 plans.

2. Selection of practices must emphasize the goal of improving water quality but minimize negative effects on production.

3. The land user must maintain practices. Field technicians must be able to certify compliance on the basis of visual inspection (annual) during any season of the year.

4. Without the use of a simplified format (BMP), conservation plans are difficult for farmers to interpret and even more difficult for those trying to certify compliance.

5. The most faithfully maintained conservation practices in Black Creek were those that provided a "visual reminder" of the contractual committment. Most all permanent practices provide this visual mark (field borders, waterways, etc.). Conversely, most management practices (tillage, rotations, etc.) do not leave an easily observed year round mark or reminder.

6. Planning to improve water quality alone will not leave a "showplace for applied conservation." Concentrating on treating primarily the critical areas on tillable land may be less apparent to the public.

7. It is not possible to conclude that BMP's are not necessary, when average gross erosion from a large area is demonstrated to be small. Neither is it possible to conclude that because soil loss as measured by the USLE is below the tolerable soil loss limits, water quality will be adequate. Losses may be large enough from relatively small critical areas to have an adverse effect on water quality. (See Section 4.9.1). This further emphasizes the need to concentrate treatment efforts on critical areas.

2.19 ADMINISTRATION

(See Section 3.3 and Section 5.1)

1. The Allen County Soil and Water Conservation District demonstrated its ability to deal with a complex program of water quality management. The availability of district personnel, paid with local funds and responsible to the board of supervisors, was important to this capability.

2. Public Information was vital to the success of the demonstration project. Because all parts of the community were informed of plans and progress at all steps of the project, rumors and potential opposition to the project did not develop.

3. The ability of the local administration to alter cost sharing rates was important both in convincing landowners to apply certain practices and in avoiding paying higher cost-share rates than necessary on practices that proved to be popular.

4. Cost of treating a watershed such as the Black Creek can be categorized. Necessary land treatment involves water quality improvement, soil protection, increasing or maintaining agricultural productive capabilities, and other conservation purposes. All of these goals should be considered in a watershed program. However, attempts should be made to assign costs to the appropriate category. All soil conservation costs for a particular watershed cannot be considered costs of improving water quality.

5. Local leadership, such as a Soil and Water Conservation District, is in the most favorable position to combine all state and local and federal programs into a total system which will balance the sometime conflicting water quality improvement goals.

6. The most cost effective method of achieving improved water quality through the best management practice approach is to concentrate remedial efforts on those critical areas within watersheds where maximum benefit can be obtained. It may not be necessary to treat every acre of every watershed to achieve realistic water quality goals.

SECTION III

Technical Approach

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3.1 SELECTION OF BLACK CREEK

One of the most important tasks undertaken during the six-month planning phase of this program was the selection of a study area which would accurately represent the Maumee Basin.

It was originally proposed that the area to be studied contain no more than 20,000 acres. This represents less than one percent of the total land area in the Maumee Basin. Because of the small size of the study area in comparison to the basin, it was necessary to find a study area which was similar to the basin in characteristics of soil type, land use, cultural practices, and anticipated future land use.

It was also considered necessary to select a study area so that it would be possible to both monitor gross results and to conduct small plot experiments.

3.1.1 Selection Criteria

To facilitate the selection of the most representative study area, the following general criteria were used:

1. The study area should include lake bed and upland soils which are reasonably representative of much of the total basin.

2. Sufficient drainageways should be present so that monitoring stations could be installed to evaluate erosion and sedimentation both from upland areas as well as where the channel enters the Maumee River.

3. Existing land uses and cultural practices should be comparable to those of the total Maumee Basin.

4. The anticipated future land uses should be typical of those expected throughout the Maumee Basin.

5. The physiography of the study area should facilitate the separation of runoff between agricultural areas and land under other uses.

6. It was considered desirable to have legal drains in the area with long time records.

7. The study area should drain directly into the Maumee River.

8. The area should be up to 20,000 acres in size.

The area selected as most nearly satisfying these criteria was the 12,038 acres which drain into Black Creek in northeastern Allen County.

3.1.2 Comparison of Area, Maumee Basin

The Black Creek watershed contains both soils and land uses which are representative of the Basin. Black Creek Study Area contains 36 percent upland soils of the silty clay loam till of the Ft. Wayne moraine in the

Blount-Morley-Pewamo association. Soils are 39 percent Blount, 38 percent Morley and 16 percent Pewamo with only 7 percent minor soils.

Below the upland, in a belt about 1-1/2 miles wide, on the lake plain, is an apron of medium-textured sediments underlying the Rensselaer-Whitaker-Oshtemo association comprising 25 percent of the watershed. Poorly-drained Rensselaer and Whitaker make up 28 and 21 percent, respectively, and excessively drained Oshtemo 6 percent. Soils such as well-drained Martinsville and Belmore, comprise the remaining 5 percent.

Toward the outer edge of this apron is a small association, making up 5 percent of the watershed, where sandy loams overlie clays at less than 3 feet. This area, in the Haskins-Hoytville association, contains 34 percent poorly-drained Haskins, 31 percent poorly-drained Nappanee, and 35 percent minor soils.

On the main lake plain itself comprising 29 percent of the watershed is the very level high clay (40-50 percent clay in subsoils) Hoytville-Nappanee association. About 48 percent is dark poorly-drained Hoytville, 23 percent is light colored Nappanee and 29 percent is of minor soils.

Alluvial soils of overflow bottomlands comprise only 5 percent of the watershed and occur mainly along the lower reaches of the Black Creek in the four miles before it enters the Maumee River. Narrow bodies occur in the upland as along Wertz Drain and the main stem of Black Creek southwest of Harlan. In this Shoals-Eel association, Shoals soils comprise 44 percent, Eel 20 percent and minor soils 27 percent.

These five soil associations comprise a range of soil conditions varying from those with 50 percent subsoil clay to those with less than 10 percent. Surface soils range from silty clays to loamy fine sands.

Only the Paulding and Latty clay areas, having over 50 percent clay in the subsoils and Ottokee and Granby, on the deep sand deposits of the north part of the lake plain east of Archbold, are not represented in the Black Creek Watershed. Data concerning these soil types is being collected in another study being undertaken by Ohio State University.

Comparing percentages by land capability classes and subclasses for the Maumee Basin with those for lands in the Black Creek Study Area reveals how closely this watershed represents conditions in the Maumee Basin as a whole. Table 1 illustrates this comparison.

The Maumee Basin is an area of intensive farming, producing corn, soybeans, wheat, sugar beets, speciality crops including tomatoes, and others for canning. Amount of land in tillage-rotation varies from about 75 to 90 percent, being least in the more rolling counties and greatest in the counties which are mostly in the lake plain. Wooded land ranges from 5 to 19 percent among counties, being greatest in the sandiest ones, and permanent pasture is generally low. The two most urbanized counties are Lucas (Ohio), where 43 percent is occupied by Toledo and its environs, and Allen (Indiana), where 12 percent is in Ft. Wayne and its surroundings.

More than 95 percent of the Black Creek Study Area is devoted to agricultural uses. This includes nearly 81 percent in cropland, 4 percent in pasture, 7 percent in woodland, 4 percent in other agricultural related

TABLE 1

Land Capability Comparisons - Maumee Basin and Black Creek Study Area

Capability Class Subclass	Percent of Land Area In Different Land Capabilities Maumee Basin	Black Creek Area
I	0.9	2.4
IIe	7.4	12.6
IIIe	3.5	3.0
IVe	1.4	1.3
IIw-IIIw	82.6	79.6
IIs-IIIs-IVs-VIe	4.2	1.1
	100.0	100.0

uses and 4 percent in urban and built-up areas. This distribution of land use compares favorably with the land use in the total Maumee River Basin as shown in Table 2.

TABLE 2

Land Use Comparisons - Maumee Basin and Black Creek Study Area

Percent of Lands in Different Uses

Land Use	Maumee Basin	Black Creek Study Area
Cropland	73	80.7
Pasture	4	4.3
Woodland	8	7.1
Urban & Built-up	9	3.6
Other	6	4.3
	100	100.0

As in the Maumee Basin, corn and soybeans are the major crops produced with an estimated 7,000 acres devoted to these crops. Small grains and meadow in rotation represent a correspondingly smaller amount of cropland acreage.

The scattered woodlands and the relatively smaller acreages of pasture and haylands in the Black Creek Study Area are typical of these land uses in the Maumee Basin.

Urban and built-up acreages for the study area are less, on a percentage basis, than for the total basin, since data for the basin includes the large population centers of Toledo and Lima, Ohio, and Ft. Wayne, Indiana. The Black Creek Study Area town of Harlan is fairly representative of the small towns and villages found in the Maumee Basin.

The Maumee Basin was one of the last areas of the Lake Erie Basin to be settled. Although Fort Wayne and Toledo were among the outposts established around 1800, it was not until the Erie Canal opened an easy water route to the region in 1825, that settlement of the Lake Erie region really flourished. The "Great Black Swamp" was the last area to be settled. It comprises the major portion of the Maumee Basin and represents the area of the formerly glacial Lake Maumee.

It was primarily the German settlers, with their knowledge of farm drainage, who brought the black soils of the former lake bed into productive use. By the middle of the nineteenth century, the dense forests of this area had been cut, and the broad, flat lands now have one of the most extensive farm drainage systems in the nation.

The Maumee Basin is today the largest and most productive agricultural area within the entire Lake Erie region. Except for some suburbanizing influences in the Toledo, Lima, and Ft. Wayne areas, the Maumee Basin is almost entirely devoted to agricultural use.

The Maumee River Basin comprises 6,608 square miles, of which 1,283 are in northeastern Indiana, 4,862 in northwestern Ohio and 463 in southern Michigan. Approximately 4,229,100 acres are involved in 26 counties: 17 in Ohio, 6 in Indiana and 3 in Michigan. In Ohio, the Basin includes all of Allen, Defiance, Henry, Paulding, Putnam, Van Wert, and Williams Counties; substantial portions of Auglaize, Fulton, Hancock, Hardin, Lucas, Mercer, and Wood Counties; and smaller areas of Seneca, Shelby, and Wyandot. Within Indiana, the Basin includes substantial portions of Adams, Allen and DeKalb Counties and smaller portions of Noble, Steuben and Wells Counties. The Michigan portion includes portions of Hillsdale and Lenawee Counties and a very small portion of Branch County.

The average annual rainfall for the Basin ranges between 28 and 36 inches. The mean annual temperature is about 50 degrees Fahrenheit, with monthly means ranging between approximately 25-30 degrees in January and February and 70-75 degrees in July and August. The mean length of the freeze-free period ranges between 150 and 180 days for most of the Basin.

The basin is roughly circular in shape, measuring about 100 miles in diameter. The Maumee River is formed at Ft. Wayne, Indiana by the confluence of the St. Joseph River and St. Mary's River. The St. Joseph River rises in Hillsdale County, Michigan, and flows southwestward. The St. Mary's River rises in Auglaize County, Ohio and flows in a northwestward direction to Ft. Wayne, where it turns abruptly to a northeastward direction before joining with the St. Joseph River to form the Maumee River. The Maumee River flows in a northeastward direction from Ft. Wayne, across the Basin to Toledo and its entrance to the Maumee Bay of Lake Erie. Two major tributaries, the Tiffin River and Auglaize River join the Maumee River from the north and south respectively, at Defiance, Ohio.

Topography ranges from a nearly flat, featureless plain across much of the center and eastern portion of the Basin to rolling hills around portions of the Basin's periphery, especially in Michigan and Indiana. The altitude ranges from nearly 1150 feet (mean sea level) in Hillsdale County, Michigan to 570 feet at the mouth of the Maumee River. Local relief ranges from a few tenths of a foot over much of the area to nearly 100 feet in the rolling hills of Michigan and Indiana. The Maumee River flows in a tortuous channel entrenched some 25 to 40 feet below the lacustrine plain. The river is generally lacking any significant terrace or flood plain development.

The erosion rates of the Maumee River Basin are often reported among the highest in the Great Lakes Basin. The estimated annual gross erosion exceeds 4-1/2 tons per acre. By contrast, the current estimated gross erosion rate for the entire Great Lakes Basin is about 2 tons per acre. Sediment yields in the Basin are relatively large, as indicated by Waterville, Ohio gage data. From 1951 to 1958, nearly 1-1/2 million tons of sediment passed the Waterville gage annually. In addition, the sediment load in the River fluctuates greatly. For example, during a 3-day period in February, 1959, nearly one-half million tons of sediment passed the Waterville gage.

Physiographically, the Maumee River Basin is essentially a nearly level plain that represents a portion of the abandoned floor of glacial Lake Maumee which occupied the Lake Erie Basin in late Pleistocene time. Abandoned shoreline deposits diverge in a northeastward and southeastward direction from Ft. Wayne. Dominant surficial deposits include lacustrine clays and sands and reworked, wave-scoured lake-bottom till. Bedrock consists predominantly of Silurian and Devonian limestones, dolomites and shales. Depth to bedrock in the Indiana portion of the Basin ranges from less than 50 feet to about 150 feet.

The Maumee River Basin is primarily agricultural, with more than 90 percent of the land in the Basin in agricultural use. Approximately 73 percent is in cropland, 4 percent in pasture, 8 percent in woodland, 6 percent in other agricultural related uses and 9 percent in urban and built-up areas. The principal crops grown are corn, soybeans, wheat, and oats, with some sugar beets. There are also significant acreages of vegetable crops and nursery stock produced within the Basin. Sales from livestock and livestock products account for about one-fourth of the income from farm sales.

Total population in the area is approximately 1,295,000 of which 50,000 reside in Michigan, 275,000 in Indiana, and the remaining 970,000 in Ohio. Toledo, Ohio and Ft. Wayne, Indiana, are the major cities with Lima, Findlay, and Defiance, Ohio, being the other major population centers. The remainder of the Basin is primarily rural with a number of smaller agriculturally-oriented communities.

The principal industries are machinery, electrical and transportation equipment manufacture, metal fabrication, petroleum refining, and food processing. Major industrial centers within the Basin are Toledo and Lima, Ohio and Ft. Wayne, Indiana.

Toledo ranks as the nation's third largest railroad center, and the city's port, which is the ninth largest in the United States, is the world's largest shipper of soft coal. Major products passing through the port include iron ore, farm products, machinery, and petroleum products. Lima, Ohio is the center of an oil distribution system for the Great Lakes and Eastern markets, while Toledo is the largest petroleum refining center between Chicago and the Eastern Seaboard.

The drainage basins of the St. Joseph and St. Mary's River which join at Ft. Wayne (where they reverse course and head toward Lake Erie), are largely controlled by glacial features of the Lake Erie glacial lobe. This lobe pushed across rocks mainly of limestone and shale and carried fine till material into present day northwest Ohio, northeast and east central Indiana and south central Michigan. During the last major stand of this glacial lobe, in its retreat some 10,000 years ago, the Fort Wayne moraine was deposited concentric to the front of the retreating lobe (see Figure 1), and this dammed up a great body of water between it and the eastward retreating ice front of the lobe. This water body was named by geologists "glacial lake Maumee," and the land area once covered by it is known today as "the lake plain."

3.1.2.1 GENERAL NATURE OF THE LAKE PLAIN

Glacial Lake Maumee did not remain long enough to influence all of the lake plain uniformly. In the west end and along the south border it merely reworked the glacial till beneath it, leveling the surface but leaving only a thin deposit of fine lake-laid sediments. Similar areas occur in the central part of the basin northeast and east of Defiance. There are a number of areas where clays are overlaid by sandy or loamy sediments up to 3 feet thick.

In areas below the steep northeastern trending flank of the Ft. Wayne moraine, deltas of loamy materials composed of eroded debris from the uplands were deposited in Lake Maumee. In this and similar border areas, temporary lake stages were recorded as beach ridges. In these areas the material deposited includes sandy and/or loamy beach ridges and deep loamy sediments on level and depressed areas. Loamy sediments were deposited only thinly over lake clays or till by action of water or wind.

Near the center of the glacial lake Maumee, fine sediments were deposited most deeply as the retreating glacial lobe stood somewhat east of Defiance. Here in an east-facing crescent is an area known as the Paulding Basin. These sediments in the Paulding Basin are higher in clay content than any other part of the Maumee Basin. This area was the center of what was once called the Maumee Swamp or Marsh. Beach ridges developed concentric to the receding lake borders just as they did at the Fort Wayne end of the glacial lake. Between Defiance and Toledo, clay loam till reworked by waters of glacial lake Maumee lies east of the Paulding Basin. The north flank of the lake plain is mantled with thick to thin sands. Sandiest areas occur just west of Bowling Green, southwest of Toledo and in the Wauseon vicinity. In these same areas, sandy loam and loam mantles only a few feet thick over clayey till or in thin mantles of loamy sand over clayey till or lake-laid clays. There is a high degree of local variation in these areas in comparison with the more clayey parts of the lake plain.

3.1.2.2 GLACIAL MORAINES AND TILL PLAINS

Clay loam till, left by the receding glacial lobe of Lake Erie occurs in parts of nine Michigan, Ohio and Indiana counties on the northwest flank of the lake plain and twelve Indiana and Ohio counties on the southwest and south. That part between St. Joseph River and the lake plain is perhaps the most rolling with best expressed morainic features and is mostly part of the Fort Wayne moraine. That southeast of Fort Wayne and east toward Findlay lies lower and is less rolling, being mostly ground moraine. Drainage of the southwest portion is through the St. Mary's River, which parallels the south flank of the Fort Wayne moraine. The eastern portion drains toward the Auglaize River and its tributaries, which flow north through the lake plain. The northern part drains through the St. Joseph

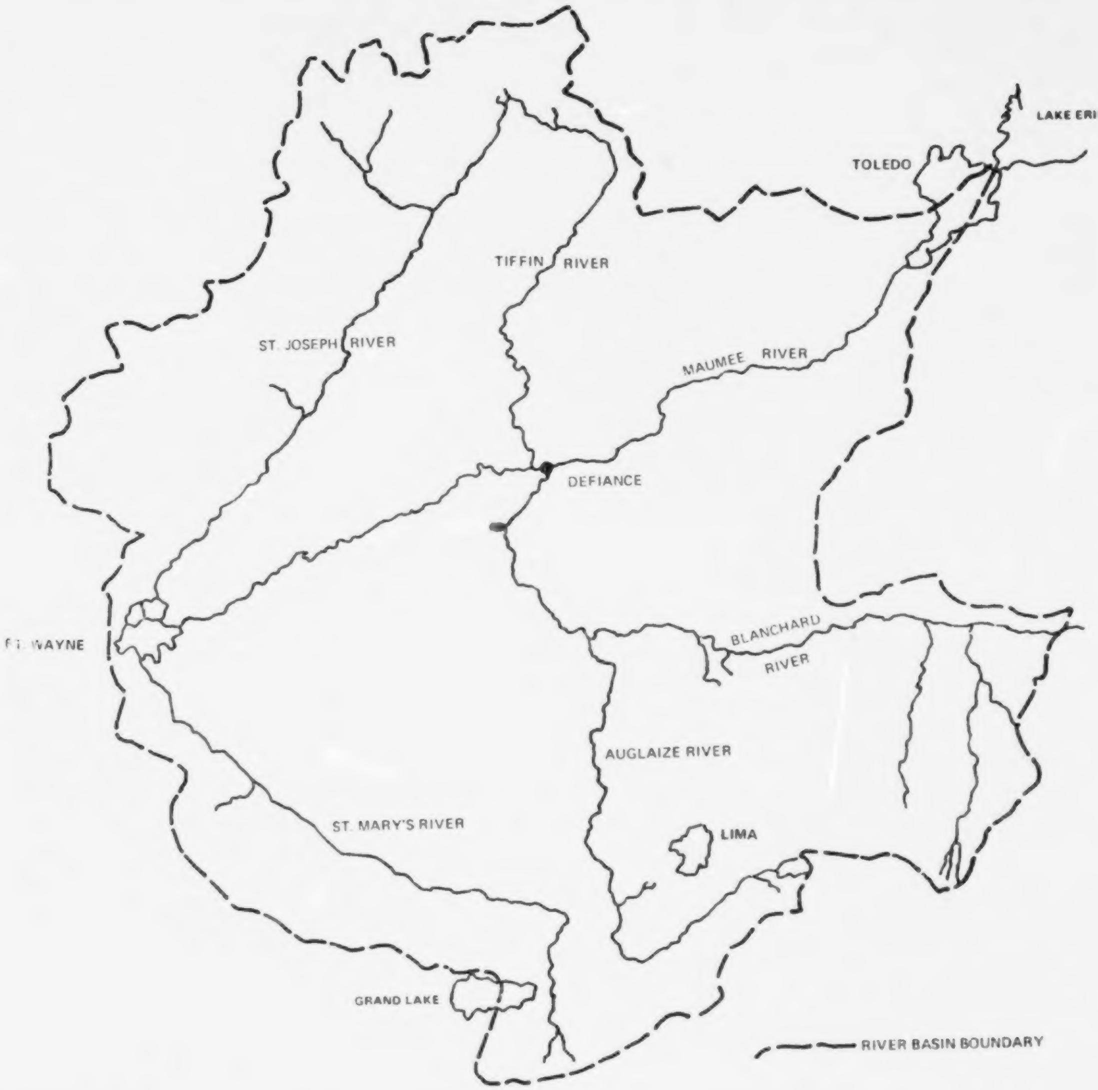

LAKE ERIE
TOLEDO
TIFFIN RIVER
ST. JOSEPH RIVER
MAUMEE RIVER
DEFIANCE
FT. WAYNE
BLANCHARD RIVER
AUGLAIZE RIVER
ST. MARY'S RIVER
LIMA
GRAND LAKE
RIVER BASIN BOUNDARY

Figure 1. Maumee Basin Map

River, which parallels the north flank of the Fort Wayne moraine, and through Tiffin River, which flows south across the lake plain.

On the south flank, where the rise to the till plain is very gradual, it is hard to determine the exact location of the lake plain boundary. Since there was apparently less eroded debris from the uplands on the south side, only a discontinuous apron of medium-textured deltaic deposits formed on the southwestern flank. However, there are a number of local lake bed deposits and muck areas in the till plain which occupy broader depressions. Also, there are lake border ridges like that one followed by U.S. Highway 30 southeast of Fort Wayne, and broader deltaic strips fringe the lake plain in the area north of Lima and east toward Findlay.

At the extreme north end of the St. Joseph River drainage in Michigan the till is sandier and more elevated and more rolling. In this area there are many valley train deposits along courses of glacial meltwater streams which are often underlaid by sand and gravel.

3.1.2.3 SOILS ASSOCIATION -- MAUMEE BASIN

Each of the soil associations of the Maumee Basin is described below. Associations 1 through 5 are soils dominantly formed in glacial till. Associations 6 through 10 are soils predominantly formed in water-deposited material, organic material, eolian material (see Figure 2).

3.1.2.3.1 Blount-Pewamo

Depressional to gently sloping, very poorly-drained to somewhat poorly-drained soils that have clayey subsoils. The landscape in this association consists of a glacial-ground moraine that is nearly level with many narrow depressions. This soil formed in glacial till. This soil association occupies about 26 percent of the watershed. Blount soils are nearly level and gently sloping and are somewhat poorly-drained. They have a surface layer of very dark grayish-brown and dark grayish-brown loam or silt loam and a subsoil that is mostly dark-brown and dark grayish-brown, mottled silty clay and clay. Pewamo soils are depressional, nearly level and are very poorly-drained. They have a surface layer of a very dark gray silty clay loam and a subsoil that is mostly dark gray or grayish-brown, mottled silty clay or silty clay loam.

3.1.2.3.2 Morley-Blount-Pewamo

Depressional to moderately steep, very poorly-drained to moderately well-drained soils that have clayey subsoils. The landscape in this association consists of a glacial moraine that is gently rolling with some depressional areas near drainageways. The soils formed in glacial till. This soil association occupies about 22 percent of the watershed. Morley soils are gently sloping to moderately steep and are moderately well-drained. They have a surface layer of very dark grayish-brown and grayish-brown silt loam and a subsoil that is mostly dark yellowish-brown and brown clay and is mottled in the lower part. Blount soils are nearly level and gently sloping and are somewhat poorly-drained. They have a surface layer of very dark grayish-brown and dark grayish-brown loam or silt loam and a subsoil that is mostly dark brown and dark grayish-brown, mottled silty clay and clay. Pewamo soils are depressional nearly level and are very clay or silty clay loam.

3.1.2.3.3 Miami-Conover

Nearly level to moderately steep, well-drained and somewhat poorly-drained soils that have loamy subsoils. The landscape in this soil association consists of a glacial moraine that is gently rolling with some depressional areas near drainageways. The soils formed in glacial till. This soil association occupies about 2 percent of the watershed. Miami soils are gently sloping to moderately steep and are well drained. They have a surface layer of dark grayish-brown loam and a subsoil that is dark brown clay loam. Conover soils are nearly level and are somewhat poorly-drained. They have a surface layer of very dark grayish brown loam and a subsoil that is mostly yellowish-brown and dark yellowish-brown, mottled clay loam.

3.1.2.3.4 Hillsdale-Fox

Gently sloping to moderately steep, well-drained soils that have loamy subsoils. The landscape in this soil association consists of glacial moraines and valley trains that are rolling with nearly level areas at the lower elevations. The soils formed in glacial till and outwash. This association occupies about 1 percent of the watershed. Hillsdale soils are gently sloping to moderately steep and are well-drained. They have a surface layer of dark grayish-brown sandy loam and a subsoil that is dark brown and dark yellowish-brown sandy loam and sandy clay loam. Fox soils are gently sloping to moderately steep and are well drained. They have a surface layer of dark grayish-brown loam and a subsoil that is dark brown clay loam and gravelly loam.

3.1.2.3.5 Hoytville-Toledo-Nappanee

Depressional to gently sloping, very poorly-drained and somewhat poorly-drained soils that have clayey subsoils. The landscape in this soil association consists of glacial lake plain and glacial till plain that is dominantly nearly level with occasional slight rises. The few sloping areas in the landscape are near deeply dissected streams. Hoytville and Nappanee soils formed in glacial till. Toledo soils formed in lacustrine sediments. This soil association occupies about 17 percent of the watershed. Hoytville soils are depressional and nearly level and are very poorly-drained. They have a surface layer that is very dark gray silty clay and a subsoil of dark grayish-brown, mottled silty clay. Toledo soils are depressional to level and are very poorly drained. They have a surface layer of very dark gray silty clay and a subsoil that is dark gray and gray, mottled silty clay. Nappanee soils are nearly level to gently sloping and are somewhat poorly-drained. They have a surface layer that is dark gray and grayish brown silt loam or silty clay loam and a subsoil that is mostly grayish brown, mottled clay.

LEGEND

SOILS DOMINATLY FORMED IN GLACIAL TILL

1 ░ BLOUNT-PEWAMO ASSOCIATION: Depressional to gently sloping, very poorly drained to somewhat poorly drained soils that have clayey subsoils.

2 ▦ MORLEY-BLOUNT-PEWAMO ASSOCIATION: Depressional to moderately steep, very poorly drained to moderately well-drained soils that have clayey subsoils.

3 ░ MIAMI-CONOVER ASSOCIATION: Nearly level to moderately steep, well-drained and somewhat poorly drained soils that have loamy subsoils.

4 ▒ HILLSDALE-FOX ASSOCIATION: Gently sloping to moderately steep, well-drained soils that have loamy subsoils.

5 □ HOYTVILLE-TOLEDO-NAPPANEE ASSOCIATION: Depressional to gently sloping, very poorly drained and somewhat poorly drained soils that have clayey subsoils.

SOILS DOMINANTLY FORMED IN WATER-DEPOSITED MATERIAL, ORGANIC MATERIAL, AND EOLIAN MATERIAL

6 ▓ CARLISLE-MONTGOMERY ASSOCIATION: Depressional and nearly level, very poorly drained soils that have organic and clayey subsoils.

7 ▩ PAULDING-LATTY-ROSELMS ASSOCIATION: Depressional and nearly level, very poorly drained and somewhat poorly drained soils that have clayey subsoils.

8 ▒ HANEY-BELLMORE-MILLGROVE ASSOCIATION: Depressional to strongly sloping, very poorly drained, moderately well-drained, and well-drained soils that have loamy subsoils.

9 ▓ MERMILL-HASKINS-WAUSEON ASSOCIATION: Depressional and nearly level, very poorly drained and somewhat poorly drained soils that have loamy and clayey subsoils.

10 ≋ OTTOKEE-GRANBY ASSOCIATION: Depressional to sloping, very poorly drained, poorly drained, moderately well-drained soils that have sandy subsoils.

Legend Figure 2

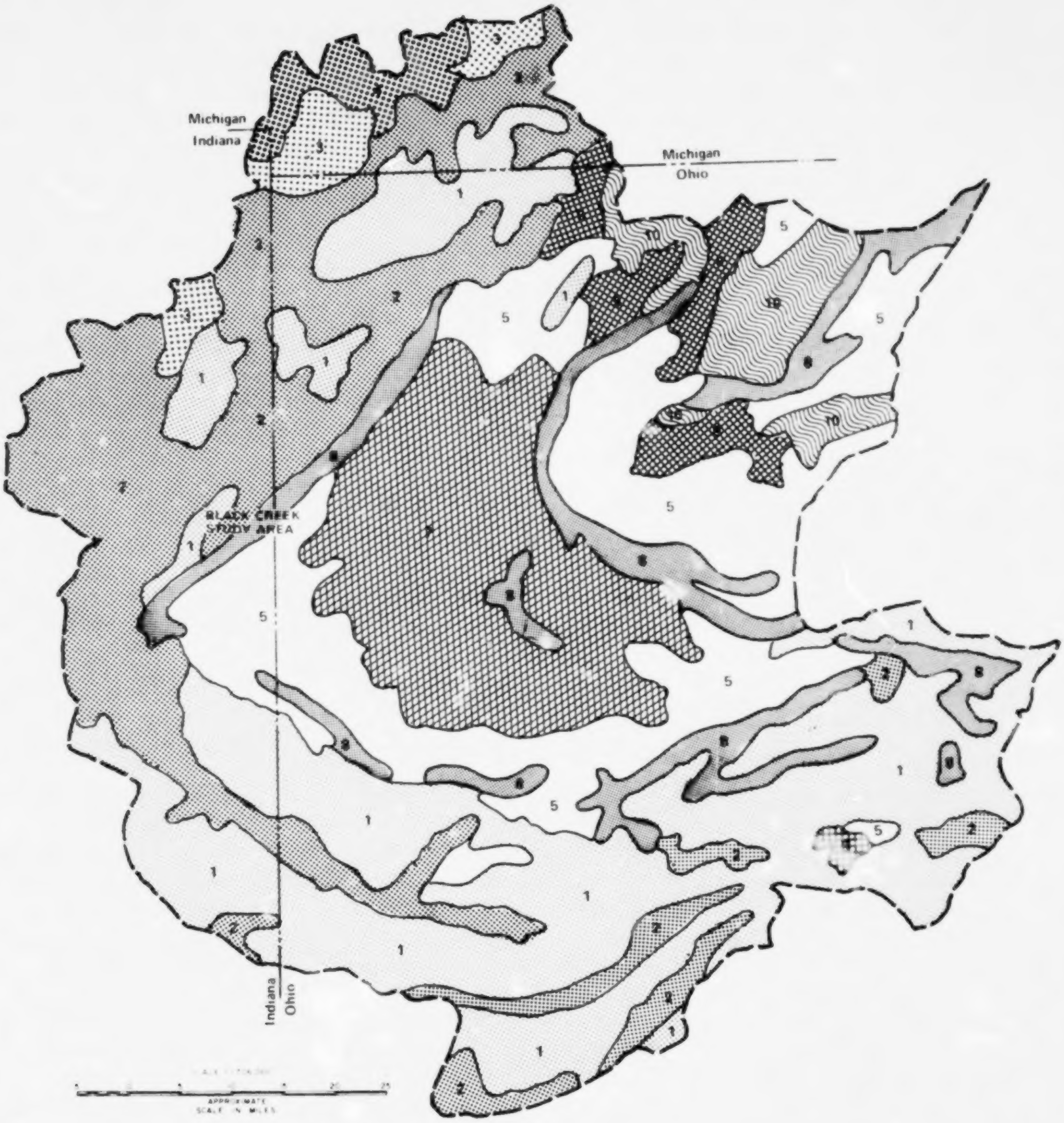

Michigan
Indiana
Michigan
Ohio
BLACK CREEK
STUDY AREA
Indiana
Ohio
1
2
3
5
8
9
10
11
10
20
25
APPROXIMATE
SCALE IN MILES

Figure 2. Soil Associations - Maumee Basin

poorly-drained. They have a surface layer of very dark gray silty clay loam and a subsoil that is mostly dark gray or grayish-brown, mottled silty

3.1.2.3.6 Carlisle-Montgomery

Depressional and nearly level, very poorly-drained soils that have organic and clayey subsoils. The landscape in this soil association consists of a local lake plain that is flat and is surrounded by a glacial ground moraine. Carlisle soils formed in organic materials. Montgomery soils formed in lacustrine sediments. This soil association occupies about 1 percent of the watershed. Carlisle soils are depressional to nearly level and are very poorly-drained. They have a surface layer of black muck and underlying material that is black and dark-reddish brown muck. Montgomery soils are depressional to nearly level and are very poorly-drained. They have a surface layer of black silty clay loam and a subsoil that is dark gray, grayish-brown, and gray silty clay loam and silty clay.

3.1.2.3.7 Paulding-Latty-Roselms

Depressional and nearly level, very poorly-drained and somewhat poorly-drained soils that have clayey subsoils. The landscape in this soil association consists of a glacial lake plain that is dominantly nearly level with occasional slight rises. A few sloping areas in the landscape are near deeply dissected streams. The soils are formed in lacustrine material. This soil association occupies about 15 percent of the watershed. Paulding soils are nearly level and are very poorly-drained. They have surface layers that are dark gray clay and subsoil that is gray and olive gray, mottled clay. Roselms soils are nearly level and are somewhat poorly-drained. They have a surface layer of dark gray silty clay loam and a subsoil that is light gray, brown , and grayish brown, mottled heavy clay.

3.1.2.3.8 Haney-Belmore-Millgrove

Depressional to strongly sloping, very poorly-drained, moderately well-drained, and well-drained soils that have loamy subsoils. The landscape in this soil association consists of long narrow sloping beach ridges rising above the terrain and nearly level glacial deltas and lake plain. The soils formed in glacial and beach ridge deltaic deposits and lacustrine sediments. This soil association occupies about 10 percent of the watershed. Any soil named in this association is more extensive than the many soils of small extent not named. Although collectively, the Haney, Belmore, and Millgrove soils do not make up the majority of the association. Haney soils are gently sloping and sloping and are moderately well-drained. They have a surface layer of dark grayish-brown loam and a subsoil that is dark brown sandy clay loam and gravelly sandy clay loam. Millgrove soils are depressional to nearly level and are very poorly-drained. They have a surface layer of dark yellowish-brown loam and a subsoil that is dark brown sandy clay loam and gravelly sandy clay loam. very dark-grayish-brown loam and a subsoil that is dark grayish brown and grayish-brown, mottled sandy loam and sandy clay loam.

3.1.2.3.9 Mermill-Haskins-Wauseon

Depressional and nearly level, very poorly-drained and somewhat poorly-drained soils that have loamy and clayey subsoils. The landscape in this soil association consists of a glacial lake plain and glacial ground moraine that are nearly level with depressional areas and some gently undulating rises. The soils formed in the outwash on glacial till or lacustrine sediments. This soil association occupies about 3 percent of the watershed. Mermill soils are depressional and nearly level and are very poorly-drained. They have a surface layer of very dark gray sandy loam. There subsoil is mottled and is dark gray, gray, and grayish-brown. It is a sandy clay loam in the upper part and a clay in the lower part. Haskins soils are nearly level and are somewhat poorly-drained. They have a surface layer of dark grayish-brown loam. The subsoil is mottled and is yellowish-brown and light yellowish-brown. It is sandy clay loam, sandy loam, and loam in the upper part and light clay in the lower part. Wauseon soils are depressional and nearly level and are very poorly-drained. They have a surface layer of very dark gray fine sandy loam. The subsoil is mottled and is dark gray, grayish-brown, and gray. It is fine sandy loam in the upper part and clay in the lower part.

3.1.2.3.10 Ottokee-Granby

Depressional to sloping, very poorly-drained, poorly-drained, and moderately well-drained soils that have sandy subsoils. The landscape in this soil association consists of beach ridges that are nearly level with gently undulating rises. The soils formed in water-laid and eolian sediments. This association occupies about 3 percent of the watershed. Ottokee soils are gently sloping and sloping and are moderately well drained. They have a surface layer of very dark grayish-brown loamy fine sand and a subsoil that is light yellowish-brown and yellowish brown, mottled loamy fine sand. Granby soils are depressional and nearly level and are very poorly-drained. They have a surface layer of black loamy sand and a subsoil that is dark gray and light brownish gray, mottled sand.

3.1.2.4 SOILS OF BLACK CREEK WATERSHED

The Black Creek study area comprises a drainage area of approximately 18.8 square miles (12,038 acres) in northeastern Allen County, Indiana. The watershed is about 13 miles northeast of Ft. Wayne. Black Creek originates about 2 miles north of the community of Harlan and flows in a south-southeasterly direction for about 4 miles, where it turns to an easterly direction for about 2 miles. Thence, after a number of abrupt changes in direction the creek flows southward for about 1-1/2 miles to the Maumee River. Black Creek is an entrenched stream throughout most of its course particularly in the lowermost 2 miles when it flows about 25 to 30 feet below the general level of the lacustrine plain. Principal tributaries are Smith-Fry Drain, Wertz Drain, Reichelderfer Drain and Upper Gorrell Drain (see Figure 3).

The mean annual rainfall at Fort Wayne is 35.31 inches. The rainfall is well distributed throughout the year, with the month of December having the least (2.09 in.) and the month of June having the most (4.17 in.). The mean annual temperature is 50.3 degrees Fahrenheit with a mean July tem-

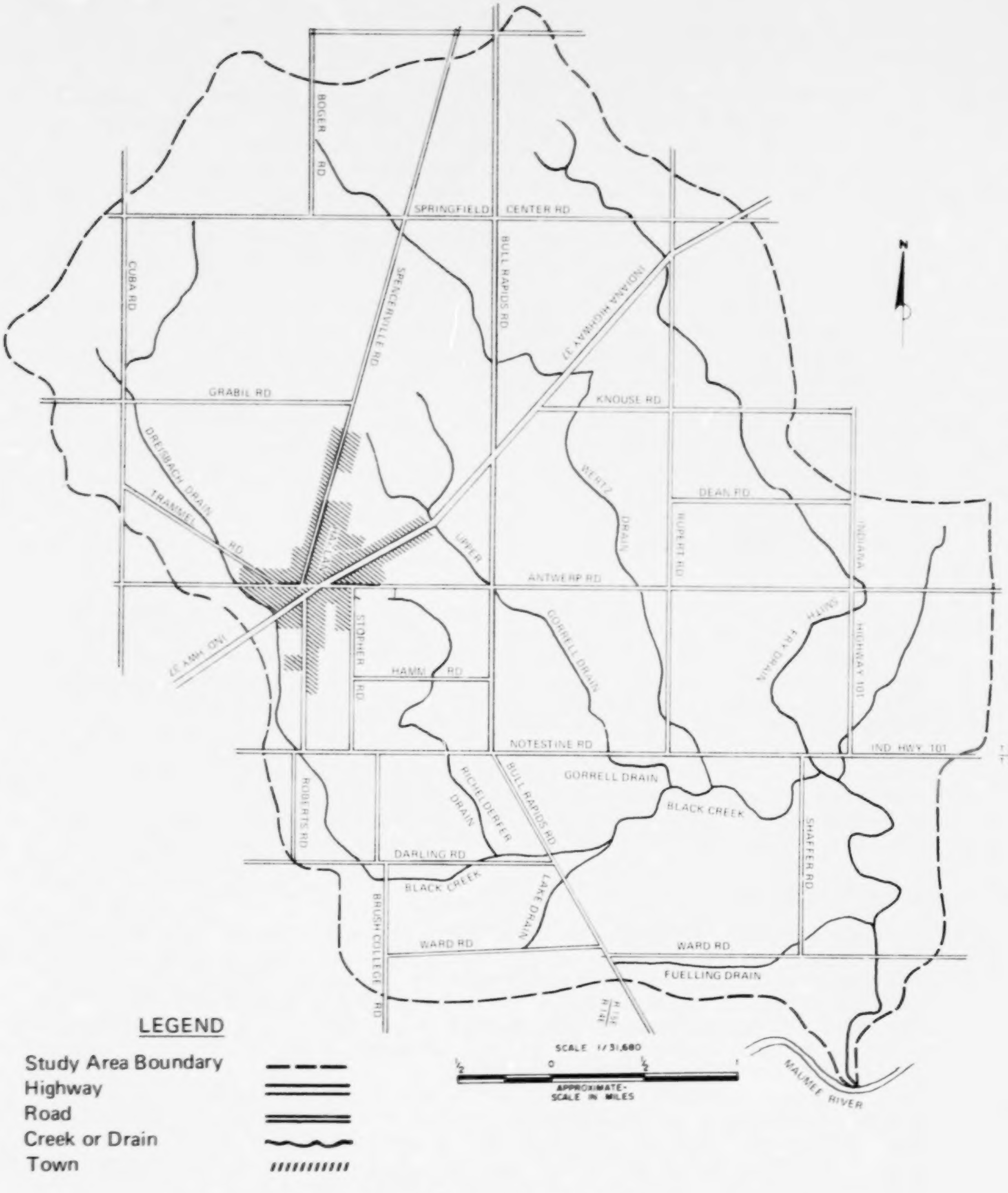

BOGER RD
SPRINGFIELD CENTER RD
CUBA RD
SPENCERVILLE RD
BULL RAPIDS RD
INDIANA HIGHWAY 37
N
GRABIL RD
KNOUSE RD
DREISBACH DRAIN
TRAMMEL RD
HARLAN
WERTZ DRAIN
DEAN RD
UPPER
RUPERT RD
INDIANA HIGHWAY 101
ANTWERP RD
STOPHER RD
GORRELL DRAIN
SMITH FRY DRAIN
IND. HWY. 37
HAMM RD
NOTESTINE RD
IND. HWY. 101
T 32N
T 31N
GORRELL DRAIN
RICHELDERFER DRAIN
BULL RAPIDS RD
BLACK CREEK
ROBERTS RD
SHAFFER RD
DARLING RD
BLACK CREEK
LAKE DRAIN
BRUSH COLLEGE RD
WARD RD
WARD RD
FUELLING DRAIN
R 14E
R 15E
SCALE 1/31,680
½
0
½
1
APPROXIMATE SCALE IN MILES
MAUMEE RIVER
LEGEND
Study Area Boundary
Highway
Road
Creek or Drain
Town

Figure 3. Black Creek Watershed

perature of 74.2 degrees and a mean January temperature of 27 degrees.

The altitude of the watershed ranges from about 710 to 850 feet above mean sea level, a maximum relief on the order of 140 feet. Local relief ranges from a fraction of a foot on portions of the lacustrine plain to as much as 40 to 50 feet in the northernmost part of the watershed and in the entrenched portion of Black Creek near the Maumee River.

The Black Creek study area is largely within the Maumee lacustrine plain (see Figure 4). Surficial deposits consist largely of wave-scoured lakebottom till. A narrow (about 1,000 foot) band of beach and shoreline deposits parallels Indiana Route 37 through the watershed. These shoreline deposits are bordered on the northwest by glacial till end-moraine deposits and to the southeast by a rather narrow (approximately 1 mile wide) band of lacustrine sands which grade into the wave-scoured lake-bottom tills. Bedrock consists of Dovonian limestone and dolomite generally less than 100 feet deep.

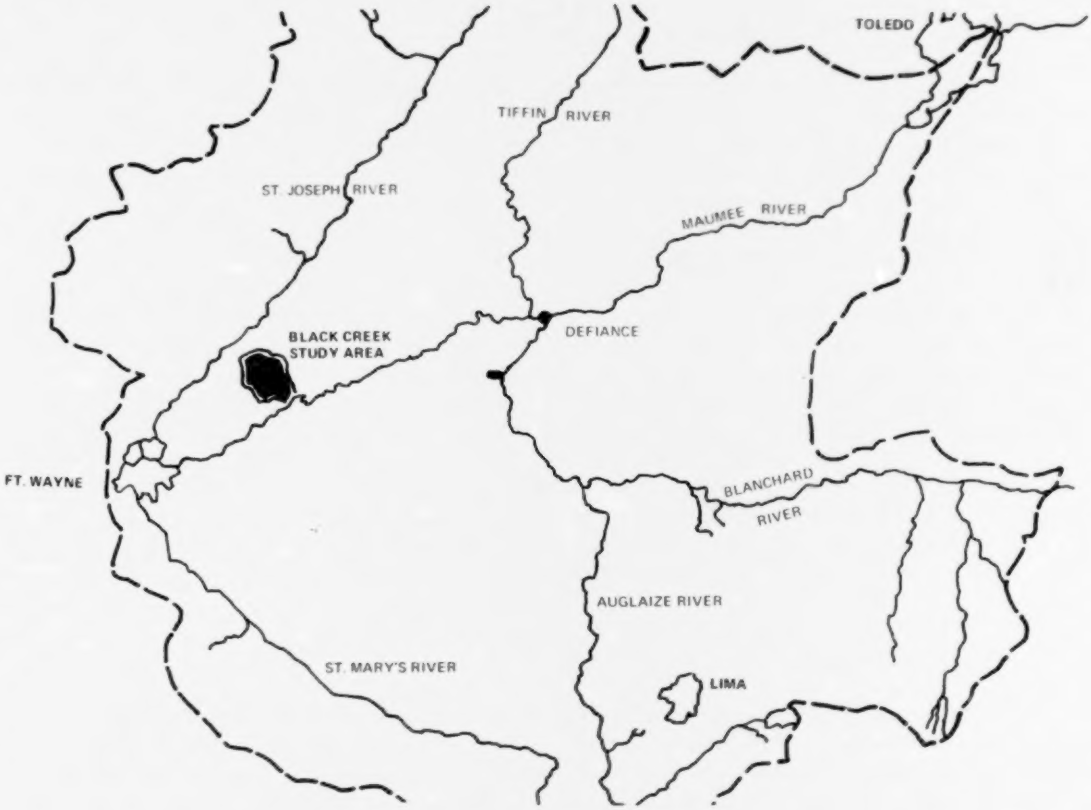

TOLEDO
TIFFIN RIVER
ST. JOSEPH RIVER
MAUMEE RIVER
BLACK CREEK STUDY AREA
DEFIANCE
FT. WAYNE
BLANCHARD RIVER
AUGLAIZE RIVER
ST. MARY'S RIVER
LIMA

Figure 4. Location of Study Area

The Black Creek Watershed area is entirely rural except for the small unincorporated community of Harlan, which is located along Indiana Route 37 in the west central portion of the watershed. Land ownership is characterized by numerous small holdings. There are 176 individual ownership tracts, of which 127 or 72% are less than 100 acres, 45 or 26% are from 100-249 acres, and only 4 (2%) are 250 acres or larger. The average value of land and buildings is approximately $1,400 per acre.

The proximity of the watershed to Ft. Wayne provides excellent opportunities for employment in needy industry and results in high off-farm employment. It is estimated that nearly 2/3 of the farm operators work off the farm. Of those operators who have off-farm employment, approximately 20% work less than 100 days off the farm, and 80% work more than 100 days off the farm.

The average market value of agricultural products sold is approximately $27,000 per farm. This is about equally divided between the two categories of cash crops and livestock, poultry and livestock and poultry products.

Each of the soil associations are described below:
(See Figure 5)

3.1.2.4.1 Blount-Morley-Pewamo

Depressional to moderately steep, very poorly-to moderately well-drained soils that have clayey subsoils; on uplands. The landscape in this association consists of glacial-ground moraine and moraine that is nearly level with many narrow depressions and is gently rolling with some depressional areas near drainageways. The soils formed in glacial till. This soil association occupies about 36 percent of the watershed. About 39 percent is made up of Blount soils, 38 percent of Morley soils, 16 percent of Pewamo soils, and 7 percent of minor soils. Blount soils are nearly level and gently sloping and are somewhat poorly-drained. They have a surface layer of very dark grayish-brown and dark grayish-brown loam or silt loam and subsoil that is mostly dark brown and dark grayish-brown, mottled silty clay and clay. Morley soils are gently sloping to moderately steep and are moderately well-drained. They have a surface layer of very dark grayish-brown and grayish brown silt loam and a subsoil that is mostly dark yellowish-brown and brown clay and is mottled in the lower part. Pewamo soils are depressional and nearly level and are very poorly-drained. They have a surface layer of very dark gray silty clay loam and a subsoil that is mostly dark gray or grayish-brown, mottled silty clay or silty clay loam.

3.1.2.4.2 Shoals-Eel

Nearly level, somewhat poorly-and moderately well-drained soils that have loamy subsoils; on bottom lands. The landscape in this association is nearly level flood plains that are adjacent to streams. The soils formed in alluvium. This soil association occupies about 5 percent of the watershed. About 44 percent is made up of the Shoals soils, 29 percent of Eel soils, and 27 percent of minor soils. Shoals soils are nearly level and are somewhat poorly-drained. They have a surface layer of dark gray and dark grayish-brown silty clay loam and a subsoil that is gray silty clay loam. Eel soils are nearly level and are moderately well-drained. They have a surface layer of dark grayish-brown and dark brown silt loam and loam and a subsoil that is brown and dark yellowish-brown, mottled light silty clay loam.

3.1.2.4.3 Hoytville-Nappanee

Depressional and nearly level, very poorly-and somewhat poorly-drained soils that have clayey subsoils; on uplands. The landscape in this soil association consists of glacial till plain that is dominantly nearly level with occasional slight rises. The soils formed in glacial till. This soil association occupies about 29 percent of the watershed. About 48 percent is made up of Hoytville soils, 23 percent of Nappanee soils, and 21 percent of minor soils. The Hoytville soils are depressional and nearly level and are very poorly-drained. They have a surface layer that is very dark gray silty clay and a subsoil of dark grayish-brown, mottled silty clay. Nappanee soils are nearly level and are somewhat poorly-drained. They have a surface layer that is dark gray and grayish-brown silt loam or silty clay loam and a subsoil that is mostly grayish-brown, mottled clay.

3.1.2.4.4 Rensselaer-Whitaker-Oshtemo

Nearly level to moderately sloping, very poorly, somewhat poorly, and somewhat excessively-drained soils that have loamy subsoils; on uplands. The landscape in this soil association consists of long narrow sloping beach ridges above the terrain and nearly level glacial deltas and lake plain. The soils formed in glacial deltaic and beach ridge deposits and lacustrine sediments. This soil association occupies about 25 percent of the watershed. About 28 percent is made up of Rensselaer soils, 21 percent of Whitaker soils, 6 percent of Oshtemo soils, and 45 percent of minor soils. Rensselaer soils are nearly level and are very poorly drained. They have a surface layer of very dark brown loam, loam to silty clay loam or mucky silty clay loam this is mottled in the lower part. The subsoil is mostly gray or strong-brown, mottled sandy loam or sandy clay loam. Whitaker soils are nearly level and are somewhat poorly drained. They have a surface layer of fine sandy loam, loam, or silt loam that is dark grayish-brown in the upper part and pale brown in the lower part. The subsoil is yellowish-brown and gray, mottled clay loam or silty clay loam. Oshtemo soils are nearly level to moderately sloping and are somewhat excessively drained. They have a surface layer that is dark-brown sandy loam or gravelly sandy loam.

3.1.2.4.5 Haskins, Hoytville

Depressional to gently sloping, somewhat poorly-and very poorly-drained soils that have loamy and clayey subsoils; on uplands. The landscape in this soil association consists of glacial-ground moraine that is nearly level with depressional areas and some gently undulating rises. Haskins soils formed in outwash on glacial till. Hoytville soils formed in glacial till. This soil association occupies about 5 percent of this watershed. About 34 percent is made up of Haskins soils, 31 percent of Hoytville soils, and 35 percent of minor soils. Haskins soils are nearly level or gently sloping and are somewhat poorly-drained. They have a surface layer of dark grayish-brown loam. The subsoil is mottled and is yellowish-brown and light yellowish brown. It is loam or sandy loam in the upper part and light clay in the lower part. Hoytville soils are depressional and nearly level and are very poorly-drained. They have a surface layer that is very dark gray silty clay and a subsoil of dark grayish-brown, mottled silty clay.

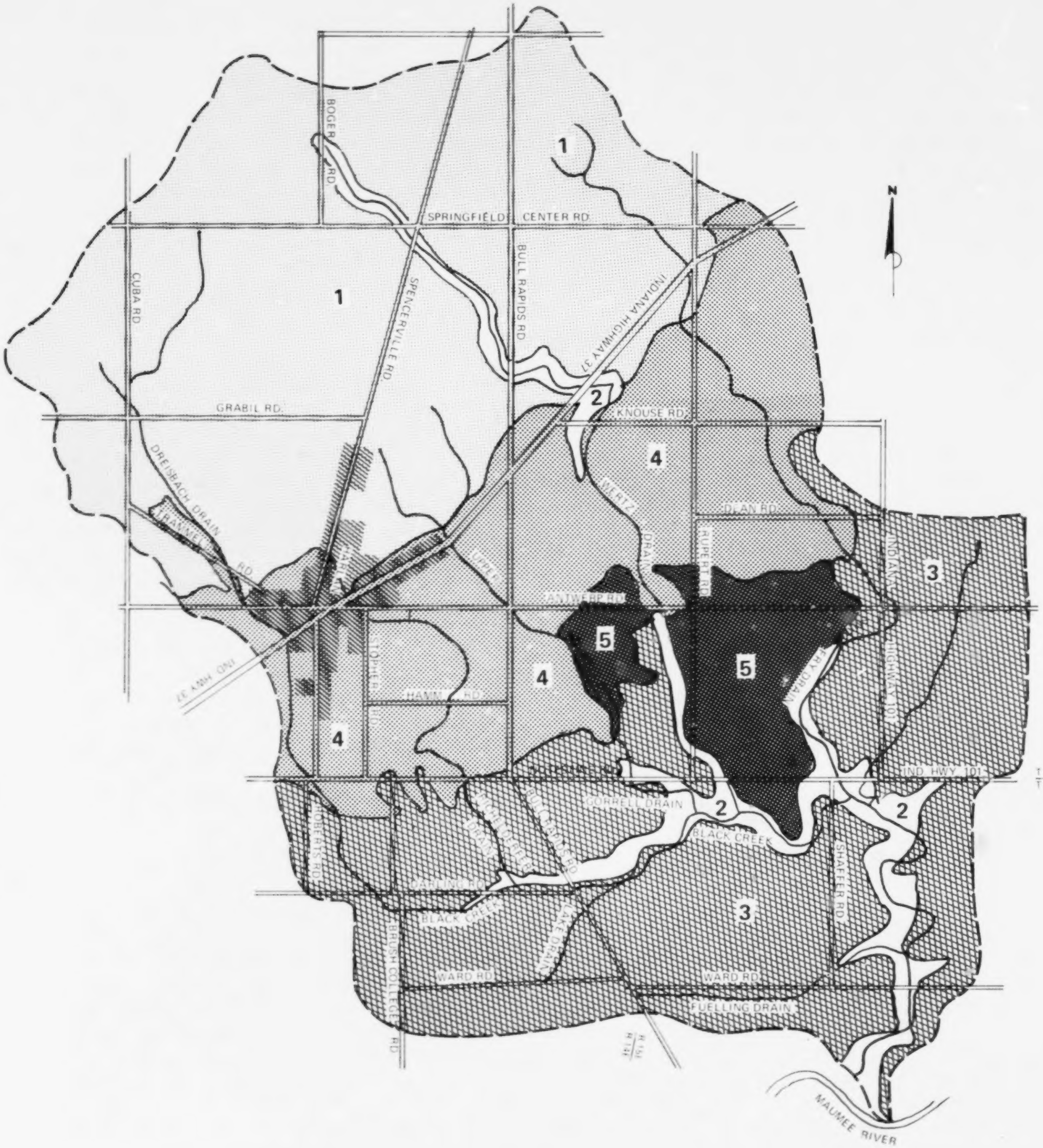

N
1
BOGER RD
SPRINGFIELD CENTER RD
CUBA RD
SPENCERVILLE RD
BULL RAPIDS RD
INDIANA HIGHWAY 37
GRABIL RD
2
KNOUSE RD
4
DREISBACH DRAIN
RD
ANTWERP RD
5
FRY DRAIN
INDIANA HIGHWAY 101
3
IND HWY 37
HAMM RD
IND HWY 101
T 32N
T 31N
GORRELL DRAIN
BLACK CREEK
SHAFFER RD
BRUSH COLLEGE RD
WARD RD
FUELLING DRAIN
MAUMEE RIVER

Figure 5. Soil Associations -- Black Creek Watershed

LEGEND

1 ░ BLOUNT-MORLEY-PEWAMO ASSOCIATION: Depressional to moderately steep, very poorly drained to moderately well-drained soils that have clayey subsoils; on uplands.

2 □ SHOALS-EEL ASSOCIATION: Nearly level, somewhat poorly drained and moderately well-drained soils that have loamy subsoils; on bottom lands.

3 ▩ HOYTVILLE-NAPPANEE ASSOCIATION: Depressional and nearly level, very poorly drained and somewhat poorly drained soils that have clayey subsoils; on uplands.

4 ▒ RENSSELAER-WHITAKER-OSHTEMO ASSOCIATION: Nearly level to moderately sloping, very poorly drained, somewhat poorly drained, and somewhat excessively drained soils that have loamy subsoils; on uplands.

5 ■ HASKINS-HOYTVILLE ASSOCIATION: Depressional to gently sloping, somewhat poorly drained and very poorly drained soils that have loamy and clayey subsoils; on uplands.

Legend Figure 5

3.1.3 Land Capability Units

The land capability unit represents a grouping of soils which share common limitations for agricultural uses and which respond to like treatment under similar conditions of use. There are 58 different kinds of soil in the Black Creek study area. These soils make up a total of 21 Land Capability Units which are used in determining land treatment needs (see Figure 6).

3.1.3.1 CAPABILITY UNIT I-1

This unit consists of deep, nearly level, well-drained, medium-textured soils of the Martinsville and Rawson series. These soils have moderate infiltration and permeability and a high available moisture capacity. These soils are productive and easy to manage and can be cropped intensively. The proper use of crop residue maintains the content of organic matter and helps to keep good tilth.

3.1.3.2 CAPABILITY UNIT I-2

This unit consists of deep, nearly level, well-drained and moderately well-drained, medium textured soils of the Eel and Genesee series. These soils are flooded occasionally in the winter and spring. They have moderate infiltration and permeability and high available moisture capacity.

3.1.3.3 CAPABILITY UNIT IIE-1

This unit consists of deep, gently sloping, well-drained, medium-textured soils. These soils are of the Martinsville, Miami, and Rawson series. They have moderate infiltration and permeability and high available moisture capacity. Erosion control is the main management need. Contour farming, diversion terraces, sod waterways, and proper crop rotation and minimum tillage are among the measures that can be used to control erosion.

3.1.3.4 CAPABILITY UNIT IIE-6

This unit consists of deep, gently sloping, moderately well-drained, medium-textured soils of the Morley series. These soils have moderate infiltration, slow permeability, and high available moisture capacity. Their natural fertility is moderate. Their content of organic matter is generally moderate or low. Erosion is a hazard, particularly in intensively cropped fields. Diversion ditches, contour tillage, stripcropping, and sod waterways are among the measures needed for control of erosion. Crop residue and intercrops help to maintain and increase the organic-matter content. Minimum tillage helps to maintain good tilth and control erosion. Wet spots created by springs or by seepage can be drained with random tile lines.

3.1.3.5 CAPABILITY UNIT IIE-9

This unit consists of gently sloping, well-drained soils of the Belmore series. These soils are moderately deep and deep to gravel and sand. They have moderately rapid infiltration, moderate permeability, and moderate available moisture capacity. Erosion is a hazard. Contour farming and sod waterways are among the measures needed for control of erosion. Proper management of crop residue is important in maintaining the organic-matter content.

3.1.3.6 CAPABILITY UNIT IIS-1

This unit consists of nearly level, well-drained, medium-textured soils of the Belmore series. These soils are moderately deep to gravel and sand. They have moderately rapid infiltration, moderate permeability, and moderate available moisture capacity. Droughtiness is a major limitation and crop residues should be left on the soil to maintain and increases the content of organic matter.

3.1.3.7 CAPABILITY UNIT IIW-1

This unit consists of deep, level and depressional, very poorly-drained, dark-colored, medium-textured to fine-textured soils. These soils are of the Brookston, Hoytsville, Lenawee, Mermill, Pewamo, Rensselaer, Washtenaw, and Westland series. They are waterlogged in periods of wet weather. They have moderate infiltration, slow permeability, and high available water capacity. Wetness is the main limitation. An adequate drainage system is needed if the common crops are to be grown. Diversion terraces that intercept runoff from adjacent uplands are beneficial. Sod outlets or structural outlets for the diversion terraces are needed. Spring tillage should be delayed until the plow layer is dry. Minimum tillage and crop residue management help to maintain good tilth.

3.1.3.8 CAPABILITY UNIT IIW-2

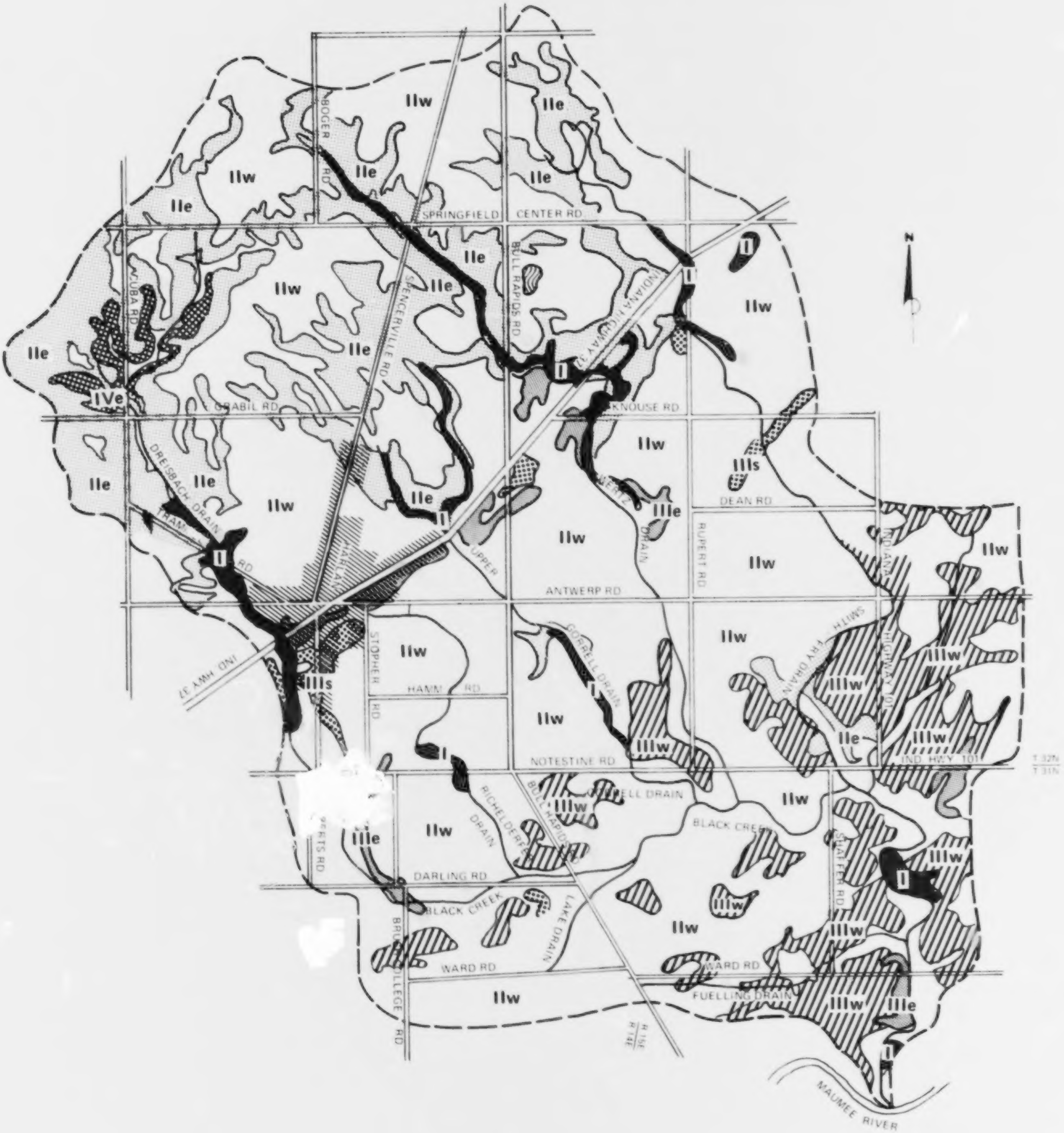
This unit consists of deep, nearly level and gently sloping somewhat poorly-drained, medium-textured or moderately coarse textured soils of the Blount, Crosby, Del Rey, Haskins, and Whitaker series. These soils have moderately slow or slow permeability and high available moisture capacity. The gently sloping areas are erodible. Wetness is the main limitation. An adequate drainage system is needed if the common crops are to be grown. Diversion terraces that intercept runoff from higher areas are beneficial. Grass waterways are needed. Other practices needed include minimum and properly timed tillage and management of crop residues.

3.1.3.9 CAPABILITY UNIT IIW-7

This unit consists of nearly level, somewhat poorly drained and very poorly-drained soils of the Shoals series. These soils are flooded occasionally, and they have a fluctuating water table. They have moderate infiltration and permeability and high available moisture capacity. Wetness is the main limitation. Adequate drainage is important. Other needed practices include conservation cropping systems, crop residue management and minimum tillage.

3.1.3.10 CAPABILITY UNIT IIIE-1

This unit consists of deep, moderately sloping, well-drained, medium-textured soils of the Martinsville and Rawson series. These soils have moderate infiltration, moderate permeability, and high available moisture capacity. Erosion is the main hazard. Contouring is the erosion control practice most applicable on the short slopes. On the few longer and more uniform slopes, stripcropping can be used. Sod waterways are needed to control erosion in drainageways.


N
IIw
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BOGER RD
SPRINGFIELD CENTER RD
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BULL RAPIDS RD
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SPENCERVILLE RD
CUBA RD
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IIe
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INDIANA HIGHWAY 37
I
IIw
IVe
GRABIL RD
I
KNOUSE RD
IIw
IIIs
DREISBACH DRAIN
IIe
IIe
IIw
IIe
IIIe
DEAN RD
I
HARLAN
I
UPPER
IIw
RUPERT RD
IIw
IIw
ANTWERP RD
IND HWY 37
IIw
GORRELL DRAIN
IIw
SMITH FRY DRAIN
IIIw
IIIw
IIIs
STOPHER RD
HAMM RD
IIw
INDIANA HIGHWAY 101
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NOTESTINE RD
IND. HWY. 101
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T 31N
GORRELL DRAIN
IIIw
IIw
IIIe
IIw
RICHELDERFER DRAIN
BULL RAPIDS RD
BLACK CREEK
SHAFFER RD
IIIw
I
DARLING RD
BLACK CREEK
LAKE DRAIN
IIIw
IIw
IIIw
BRUNSON COLLEGE RD
WARD RD
WARD RD
IIw
FUELLING DRAIN
IIIw
IIIe
R 15E
R 14E
I
MAUMEE RIVER

Figure 6. Land Capabilities Units -- Black Creek Watershed

LEGEND

I	■	CLASS I Land has few hazards that limit its use. It is nearly level, deep, generally well-drained and suited for intensive cultivation with good management.
IIw	□	CLASS IIw Land is very good cropland but has wetness hazards which may be overcome with proper installation of drainage practices and use of conservation management systems.
IIe	□	CLASS IIe Land is very good cropland but has erosion hazards which may be easily overcome with proper installation of practices and conservation management systems.
IIIw	▨	CLASS IIIw Land is good cropland but has severe wetness hazards that will require careful soil management, and installation of more intensive drainage systems to be good cropland. The hazards may limit the intensity and choice of cultivated crops.
IIIe	▩	CLASS IIIe Land is good cropland but severe wind and/or erosion hazards may limit the intensity of use and choice of crops. Carefully selected conservation practices must be considered in use of this land for crops. The sandy soils also have a droughty hazard.
IIIs	░	CLASS IIIs Land is considered good cropland but droughtiness is a severe hazard. Careful soil management including irrigation may be considered in the use of this land for crops.
IVe	▦	CLASS IVe Land has very severe erosion hazard due to slope which limits its use for cultivated crops. It requires very careful management including special conservation practices when cultivated.

Legend Figure 6

3.1.3.11 CAPABILITY UNIT IIIE-6

This unit consists of deep, gently sloping and moderately sloping, moderately well-drained, medium-textured soils of the Morley series. These soils range from uneroded to severely eroded. They have moderate infiltration, slow permeability, and high available moisture capacity. Erosion is a hazard, particularly in intensively cropped fields. Diversion ditches, contour tillage, stripcropping, sod waterways, crop residue management and minimum tillage are among the measures needed for control of erosion.

3.1.3.12 CAPABILITY UNIT IIIE-9

This unit consists of Fox loam, 6 to 12 percent slopes, moderately eroded, a well-drained soil. This soil is moderately deep to sand and gravel. It has moderate permeability and moderate available moisture capacity. This soil occurs as small areas, many of which are managed along with less sloping soils that can be used more intensively. As a result, considerable erosion has taken place. Erosion is the main hazard. Contour tillage, minimum tillage, mulch tillage, and a suitable cropping system help to control erosion.

3.1.3.13 CAPABILITY UNIT IIIE-11

This unit consists of deep, gently sloping, well-drained soils of the St. Clair series. These soils range from uneroded to moderately eroded. They have moderate infiltration, slow permeability, and high available moisture capacity. Erosion is the main hazard. Maintaining good tilth and increasing the content or organic matter are problems. Diversion terraces and contour tillage help to control runoff and erosion. Permanent grassed waterways are needed to prevent gullying of natural drainageways. Minimum tillage, a suitable cropping system, and proper use of crop residue help to improve tilth and to increase the content of organic matter.

3.1.3.14 CAPABILITY UNIT IIIE-13

This unit consists of deep, gently sloping and moderately sloping, well-drained and somewhat excessively drained, moderately coarse textured soils for the Belmore and Oshtemo series. These soils have moderately rapid infiltration, moderate and moderately rapid permeability, and low available moisture capacity. Erosion is the main hazard, and droughtiness is a serious limitation. Contour tillage, crop residue management, and minimum tillage help to control erosion.

3.1.3.15 CAPABILITY UNIT IIIS-2

This unit consists of deep, nearly level, somewhat excessively-drained moderately coarse textured soils of the Oshtemo series. These soils have moderately rapid infiltration and permeability and low available moisture capacity. Droughtiness is the main limitation to use.

3.1.3.16 CAPABILITY UNIT IIIW-2

This unit consists of deep, nearly level, very poorly-drained, dark-colored, moderately fine textured or fine textured soils of the Montgomery series. These soils become waterlogged in periods of wet weather and are slow to dry out in spring. They have very slow infiltration and permeability and high available water capacity. Wetness is the major limitation. Maintaining good tilth is a problem. An adequate drainage system is needed. It is necessary to keep tillage to a minimum. Crop residue management in the cropping system is needed.

3.1.3.17 CAPABILITY UNIT IVE-6

This unit consists of deep, moderately sloping and strongly sloping, moderately well-drained, medium-textured and moderately fine textured soils of the Morley series. These soils have been eroded so severely that the present surface layer consists almost entirely of material from the subsoil. They have slow to moderate infiltration, slow permeability, and high available moisture capacity. Erosion is the main hazard. Contour cultivation, diversion terraces, and sod waterways help to control runoff and erosion. Crop residue management and minimum tillage also improve tilth and reduce runoff.

3.1.3.18 CAPABILITY UNIT IVE-11

This unit consists of St. Clair silty clay loam, 6 to 12 percent slopes, moderately eroded, a deep, well-drained or moderately well-drained soil. This soil has moderate infiltration, slow permeability, and high available moisture capacity. Erosion is the main hazard. Permanent sod in natural drainageways helps to control gully erosion. Contour cultivation, crop residue management, and minimum tillage are effective in the control of runoff and erosion.

3.1.3.19 CAPABILITY UNIT IVE-1

This unit consists of deep, nearly level and gently sloping well-drained, coarse-textured soils of the Plainfield series. These soils have rapid permeability and low available moisture-holding capacity. Droughtiness is the main limitation. Crop residue management minimum tillage and cover crops, help to control wind erosion.

3.1.3.20 CAPABILITY UNIT VIE-1

This unit consists of deep, strongly sloping, severely eroded, moderately well-drained, medium-textured soils of the Morley series. These soils have slow to moderate infiltration, slow permeability, and high available moisture capacity. The soils are too steep and too erodible to be suitable for cultivation, except what is necessary for the establishment of permanent pasture. Erosion is the main hazard. A vegetative cover and protection from overgrazing help to control erosion.

Major land uses in the Black Creek Study Area include cropland, 80.7 percent; grassland, 4.3 percent; woodland, 7.1 percent; wildlife and recreation, 2.7 percent; urban and built-up, 3.6 percent and farmstead, 1.6 percent. Lands categorized as urban and built-up include the acreages occupied by the town of Harlan as well as county roads, highways, schools, and cemeteries. Table 3 shows present acreage for each capability unit in the Black Creek Study Area.

The pattern of land use is expected to remain relatively stable over the next five years. However, some minor changes can be anticipated as indicated by recent trends and in response to planned land use. It is es-

TABLE 3
Soils Data By Land Capability - Black Creek Study Area

Land Capability Unit	Acres	Major Soils Series	Major Hazard
I-1	48	Martinsville, Rawson	None
I-2	239	Eel, Genesee	Flooding
IIe-1	206	Martinsville, Miami, Rawson	Erosion
IIe-6	1299	Morely	Erosion
IIe-9	10	Belmore	Erosion
IIs-1	3	Belmore	Droughtiness
IIw-1	4435	Pewamo, Hoytville, Brookston	Wetness
IIw-2	3698	Blount, Crosby, Haskins	Wetness
IIw-7	384	Shoals	Wetness
IIIe-1	3	Martinsville, Rawson	Erosion
IIIe-6	127	Morley	Erosion
IIIe-9	5	Fox	Erosion
IIIe-11	50	St. Clair	Erosion
IIIe-13	171	Belmore, Oshtemo	Erosion, Droughtiness
IIIs-2	102	Oshtemo	Droughtiness
IIIw-2	3	Montgomery	Wetness
IIIw-6	1074	Nappanee	Wetness
IVe-6	137	Morley	Erosion
IVe-11	24	St. Clair	Erosion
IVs-1	5	Plainfield	Droughtiness
VIe-1	15	Morley	Erosion
TOTAL	12038		

timated that urban and built-up acreage will increase by 118 acres as some of the better-drained woodland and cropland along county roads and highways are converted to residential use. A net decrease of 143 acres of cropland and 70 acres of woodland is projected. The acreage used for wildlife and recreation should increase by 118 acres.

3.2 DESIGN OF LAND TREATMENT

The specific goals of the Black Creek project for treatment of land in the watershed were established during the development of the work plan in late 1972 and early 1973.

The concept then was that no traditional practice of soil conservation should be eliminated from the plan so that each would receive a fair evaluation as to its potential impact on water quality. In all, 33 practices were specified for cost-sharing and potential application in the project.

These practices and the goals established for them are reported in Table 4, which is based on Table A-10 of the original work plan.

Assignment of quantities of practice within the general framework of the project was based largely on the experience of members of the state and local offices of the Soil Conservation Service. Personnel drew heavily on experience in the design of small watershed projects and on experience in previous programs of accelerated land treatment.

In fact, the practices described in Table 4, cover a variety of conservation purposes, a point which is developed more completely later in this report. In general, practices can be classified as:

(a) those which primarily affect water quality,
(b) those which primarily result in protection of the soil resource,
(c) those which primarily lead to increased crop production, and
(d) those which primarily fulfill other conservation purposes.

A decision not to attempt to classify practices in this manner at the beginning of the project, although most project personnel were aware that practices could be so classified, represented both lack of experience in developing plans primarily aimed at improved water quality and a desire to give each practice a fair evaluation.

In fact, none of the four categories, listed above can fairly be labeled as undesirable categories and the relative importance of each must be considered in planning a program for a specific watershed. In some cases, practices are complementary. In other cases, there may be a conflict between opposing uses, e.g., it may not be possible to achieve both maximum water quality and maximum crop production simultaneously.

Similarly, while it may be desirable to consider all four categories when designing land treatment for a specific watershed, policy decisions may suggest that funds or technical assistance necessary to carry out certain practices be obtained from varying sources. This point is also further developed in Section 5.1.

3.2.1 Role of SCS

The Soil Conservation Service of the U.S. Department of Agriculture has been responsible for technical assistance to landowners and to the Allen County SWCD during the Black Creek project. This assistance has taken the form of both planning assistance -- the overall plan for watershed ap-

TABLE 4
Land Treatment Goals and Estimated Installation Costs

Land Treatment Goals and Estimated Installation Costs					YEARLY GOALS AND PROJECT INSTALLATION COSTS (DOLLARS)									
Item	Unit	Goal	Unit Price *	Total Cost	Oct.72-Oct.73		Oct.73-Oct.74		Oct.74-Oct.75		Oct.75-Oct.76		Oct.76-Oct.77	
					Goal	Cost	Goal	Cost	Goal	Cost	Goal	Cost	Goal	Cost
Land Adequately Treated	Ac.	10,573			671		2,612		3,533		3,757			
Cropland to Grassland	Ac.	4					4							
Cropland to Woodland	Ac.	10							10					
Cropland to Wildlife & Rec.	Ac.	88					20		23		45			
Cropland to Other	Ac.	35					8		11		16			
District Cooperators	No.	148			40		63		29		19			
District Cooperators	Ac.	7,747			2,034		2,141		1,538		977			
Conservation Plans	No.	170			16		53		57		44			
Conservation Plans	Ac.	10,641			1,002		3,317		3,589		2,733			
Conservation Plans Revised	No.	6			3		3							
Conservation Plans Revised	Ac.	1,040			520		520							
Conservation Cropping System	Ac.	7,418	1.50	11,127	600	900	1,978	2,967	2,637	3,955	2,203	3,305		
Contour Farming	Ac.	769	2.00	1,538	-	-	205	410	273	546	291	582		
Critical Area Planting	Ac.	10	400.00	4,000	1	400	2	800	4	1,600	3	1,200		
Crop Residue Management	Ac.	7,491	1.50	11,236	600	900	1,997	2,995	2,663	3,995	2,231	3,346		
Diversions	Ft.	39,200	0.50	19,600	2,000	1,000	10,000	5,000	13,500	6,750	13,100	6,550		
Farmstead & Feedlot Windbreaks	Ac.	75	80.00	6,000	-	-	21	1,680	28	2,240	26	2,080		
Field Border	Ft.	288,320	0.30	86,496	25,000	7,500	51,866	15,560	102,488	30,747	108,966	32,689		
Field Windbreak	Ft.	12,000	0.05	600	-	-	3,199	160	4,265	213	2,536	227		
Grade Stabilization Structures	No.	368	500.00	184,000	30	15,000	88	44,000	117	58,500	133	66,500		
Grassed Waterway or Outlet	Ac.	68	450.00	30,600	3	1,350	18	8,100	24	10,800	17	7,650		
Holding Ponds & Tanks	No.	11	5,600.00	61,600	1	5,600	2	11,200	4	22,400	4	22,400		
Land Smoothing	Ac.	300	75.00	22,500	-	-	80	6,000	107	8,025	113	8,475		
Livestock Exclusion	Ac.	215	20.00	4,300	20	400	47	940	66	1,320	82	1,640		
Livestock Watering Facility	No.	28	200.00	5,600	2	400	5	1,000	9	1,800	12	2,400		
Minimum Tillage	Ac.	7,656	6.50	49,764	300	1,950	2,041	13,266	2,722	17,694	2,593	16,854		
Pasture & Hayland Management	Ac.	402	18.00	7,236	20	360	87	1,566	143	2,574	152	2,736		
Pasture & Hayland Planting	Ac.	501	70.00	35,070	50	3,500	124	8,680	165	11,550	162	11,340		
Pond	No.	39	2,500.00	97,500	2	5,000	8	20,000	14	35,000	15	37,500		
Protection During Development		118	100.00	11,800	3	300	28	2,800	42	4,200	45	4,500		
Recreation Area Improvement	Ac.	12	200.00	2,400	-	-	3	600	4	800	5	1,000		
Sediment Control Basin	No.	6	5,000.00	30,000	6	30,000					-	-		
Stream Channel Stabilization(1)	Ft.	90,000	0.50	45,000	3,000	1,500	23,594	11,797	31,458	15,729	31,948	15,974		
Stream Channel Stabilization(2)	Ft.	6,000	6.00	36,000	-	-	2,000	12,000	2,000	12,000	2,000	12,000		
Streambank Protection	Ft.	122,000	2.00	244,000	10,000	20,000	32,525	65,050	43,365	86,730	36,110	72,220		
Stripcropping	Ac.	300	5.00	1,500	-	-	80	400	105	525	115	575		
Surface Drains	Ft.	90,500	0.40	36,200	3,000	1,200	24,127	9,651	32,170	12,868	31,203	12,481		
Terraces, Gradient	Ft.	11,000	0.25	2,750	-	-	2,933	733	3,910	978	4,157	1,039		
Terraces, Parallel	Ft.	11,000	0.75	8,250	-	-	2,933	2,200	3,911	2,933	4,156	3,117		
Tile Drains (3)	Ft.	200,300	0.40	80,120	16,068	6,427	50,360	20,144	68,360	27,344	65,512	26,205		
Tree Planting	Ac.	10	80.00	800	-	-	3	240	4	320	3	240		
Wildlife Habitat Management	Ac.	222	70.00	15,540	-	-	59	4,130	79	5,530	84	5,880		
Woodland Improved Harvesting	Ac.	200	15.00	3,000	20	300	40	600	74	1,110	66	990		
Woodland Improvement	Ac.	610	20.00	12,200	20	400	143	2,860	217	4,340	230	4,600		
Woodland Pruning	Ac.	50	30.00	1,500	10	300	10	300	13	390	17	510		
SUBTOTAL				1,169,827		107,687		277,829		395,596		388,805		
TECHNICAL ASSISTANCE (SCS)				197,364		46,500	(4)	36,843		55,201		45,795		13,025
TOTAL INSTALLATION COSTS				1,367,191		154,187		314,672		450,797		434,510		13,025

plication, individual conservation plans, etc. -- and technical engineering assistance, i.e., the design of practices to be applied.

Over the five years of the project, SCS estimates that 22,793 man-hours were applied to the Black Creek project. Of these hours, 14,509 involved planning or engineering assistance. This further can be broken down into 6,099 for planning time, 4,400 hours in application, and 3,577 hours of planning and application on projects which involved more than one landowner. The balance represents administration and special sources.

Planners developed 133 individual conservation plans for landowners during the project. This breaks down to about 46 hours per plan or a cost, based on reimbursement to SCS, of nearly $340 per plan.

These time and cost figures are critical to understanding the approach taken to planning for improved water quality in the Black Creek Watershed. Individual conservation plans served as the basis for contracts with landowners and resulted in the "total approach" of the Black Creek project as opposed to a less coordinated "practice-at-a-time" approach which has been criticized in other areas.

More detail on costs of technical assistance by SCS is included in the section of report on costs.

3.2.2 Procedures of the SWCD Board

Soil and Water Conservation Districts have cooperated with county ASCS Committees for many years in allocating funds for soil conservation programs under USDA projects. In the case of the Black Creek project, funds were controlled directly by the Soil Conservation District. Cost sharing rates were flexible, subject only to the requirement that the federal share of the total project not exceed 75 percent of the total project cost.

As a result, an early responsibility of the Board of Supervisors was to establish cost sharing rates for practices to be applied during the Black Creek project. In order to do this, the Board ranked project goals as easy, normal, moderately difficult, difficult or very difficult to achieve. The initial rankings, as determined by the Board, are listed in Table 5.

Cost-share rates were based on this evaluation. Higher rates were set on practices which, it was assumed, would be difficult to convince farmers to use. In general, the initial determination of the Board of Supervisors proved to be accurate. There were exceptions, however. For example, field borders, which the Board thought would be very difficult to apply, proved to be popular with rural landowners. The initial cost-share rate, set for field borders by the Board, was reduced before the end of the project.

In other cases, as much as 90 percent cost sharing was paid to achieve cooperation. It is doubtful that the project would have been as successful as it was if the Board had not retained this ability to make changes in cost-share rates or other incentives.

To make sure that uniform procedures were followed in the conduct of the project, an operations manual was prepared by the project staff and adopted by the Board. The operations manual provided a guide for dealing with anticipated problems that could arise during the program. It spelled out procedures for actions to be taken in the event a contract was not fol-

TABLE 5
Degree of Difficulty for Black Creek Conservation Goals

District Cooperators	Easy
Conservation Plans	Normal
Land Adequately Treated	Normal
Conservation Cropping System	Difficult
Critical Area Planting	Moderately Difficult
Crop Residue Management	Difficult
Diversions	Difficult
Farmstead and Feedlot Windbreak	Normal
Field Border	Very Difficult
Field Windbreak	Normal
Grade Stabilization Structure	Moderately Difficult
Grassed Waterway or Outlet	Difficult
Holding Ponds and Tanks	Easy
Livestock Exclusion	Moderately Difficult
Livestock Watering Facility	Moderately Difficult
Minimum Tillage	Difficult
Pasture and Hayland Management	Difficult
Pasture and Hayland Planting	Difficult
Pond	Easy
Recreation Area Improvement	Normal
Sediment Control Basin	Difficult
Stream Channel Stabilization	Moderately to Very Difficult
Streambank Protection	Moderately Difficult
Stripcropping	Very Difficult
Surface Drains	Difficult
Terraces, Gradient	Very Difficult
Terraces, Parallel	Very Difficult
Tile Drains	Difficult
Tree Planting	Very Difficult
Wildlife Habitat Management	Moderately Difficult
Woodland Improved Harvesting	Moderately Difficult
Woodland Improvement	Difficult

lowed by participating landowners, what to do in the event of the death of a cooperator, and what the responsibilities of all parties were in the event that land ownership changed.

Adoption of the operations manual made it possible to avoid ad hoc decisions. Even though all of the eventualities anticipated in the manual did not, in fact, take place, the Board considers that the time spent on its preparation was worthwhile.

Administrative control of the project was retained by the Board of Supervisors, even though the day-to-day operation was delegated to the project director. This control was maintained by requiring Board approval at several critical stages in the process of working with cooperators. The Board was required to approve each initial agreement in which a landowner became a "cooperator" of the district. The Board further was required to approve the conservation plan on which compliance and possible cost-sharing was based. This approval came in the form of a contract with the landowner. Finally, the Board was required to approve payment of claims made under the contract. In this way, the Board was not only regularly informed of the progress being made under the project, but also had the opportunity to make changes, if necessary, in procedures, payment rates, and certification of compliance.

3.3 TECHNICAL APPROACH

Detailed monitoring of water quality and other parameters has been carried out since the beginning of the Black Creek Project. This was necessary to fulfill the purpose of understanding the mechanisms whereby land use affects water quality. Monitoring was carried out by both Purdue and University of Illinois personnel. Both carried out water quality monitoring, and each investigated other parameters. The monitoring scheme for the Black Creek watershed is described in this section.

3.3.1 Sampling

3.3.1.1 MAJOR MONITORING SITES -- PURDUE

Purdue has collected regular grab samples at the sites listed here. These locations are identified in Figure 7.

3.3.1.1.1 Water Quality Sampling Sites

1. Killian Drain at Notestine Road
2. Smith-Fry Drain at Notestine Road
3. Wertz Drain at Notestine Road
4. Gorrell Drain at Notestine Road
5. Richelderfer Drain at Notestine Road
6. Black Creek at Brush College Road
7. Lake Drain at Bull Rapids Road
8. Wertz Drain at St. Hwy. #37
9. Dreisbach at Trammel Road
10. Dreisbach at St. Hwy. #37
11. Fuelling Drain at Ward Road
12. Black Creek at Ward Road
13. Wann Drain at Killian Road
14. Maumee River at St. Hwy. #101
15. Fuelling Drain below sediment basin
16. Richelderfer Drain at Stopher Road
17. St. Mary's River at Ferguson Road
18. St. Joseph River at Van-Zile Road
19. Dreisbach at Cuba Road (end waterway)

Rainfall amount was measured regularly at the following seven locations. Periodically samples of rainfall were analyzed for water quality parameters.

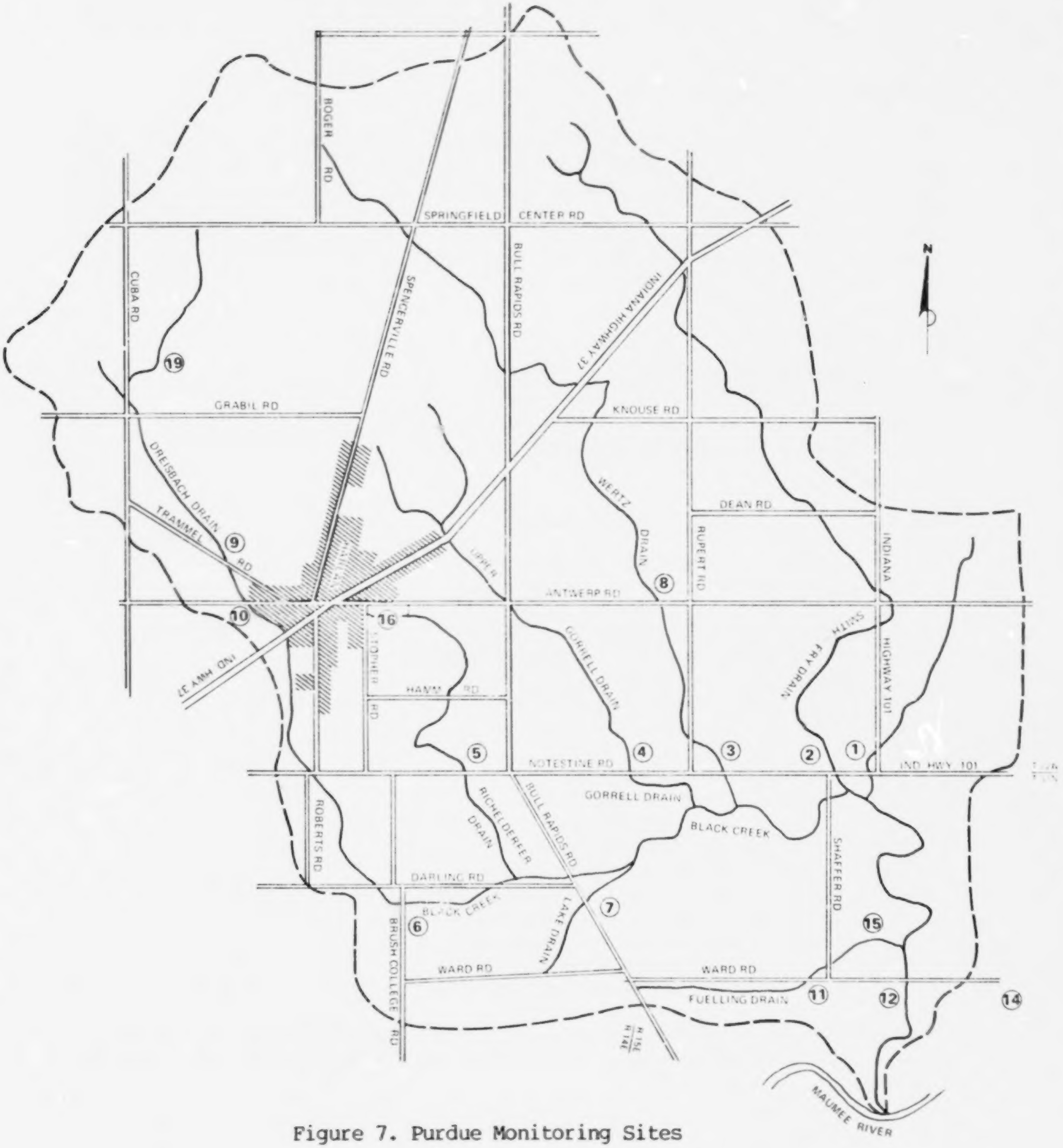
N
ROGER RD
SPRINGFIELD
CENTER RD
CUBA RD
SPENCERVILLE RD
BULL RAPIDS RD
INDIANA HIGHWAY 37
19
GRABIL RD
KNOUSE RD
DREISBACH DRAIN
TRAMMEL RD
9
WERTZ DRAIN
DEAN RD
RUPERT RD
INDIANA HIGHWAY 101
UPPER
ANTWERP RD
8
10
16
IND HWY 37
STOPHER RD
GORRELL DRAIN
SMITH FRY DRAIN
HAMM RD
5
4
3
2
1
NOTESTINE RD
IND HWY 101
GORRELL DRAIN
BLACK CREEK
ROBERTS RD
RICHELDERFER DRAIN
BULL RAPIDS RD
SHAFFER RD
DARLING RD
BLACK CREEK
7
6
LAKE DRAIN
15
BRUSH COLLEGE RD
WARD RD
WARD RD
FUELLING DRAIN
11
12
14
MAUMEE RIVER

Figure 7. Purdue Monitoring Sites

3.3.1.1.2 Raingage Sites

1. Approximately 1/8 mile west of Cuba Road on Springfield Center Road.
2. Southwest corner junction Springfield Center Road and Spencerville Road.
3. Approximately 1/4 miles east of Spencerville Road on Grabill Road.
4. Northwest corner junction of St. Hwy. #37 and Ruppert Road.
8. Approximately 1/4 mile south of junction Notestine Road and Ruppert Road.
9. Fuelling Drain and Shaffer Road.
20. 1/4 mile east of St. Hwy. #101 and Gar Creek Road ('75).

Two sediment basins, the smaller being designated a desilting basin, were constructed for study of the impact of this practice on water quality. These were located the following locations.

3.3.1.1.3 Sediment Basin Study Sites

1. Fuelling Drain east of Shaffer Road
2. Desilting basin in Black approximately 3/4 mile east of Shaffer Road and 1/4 mile south of St. Hwy. #101

Stage recorders and other methods of measuring stream flow were installed at nine locations in the watershed. Stream flow data is necessary to convert concentrations measured of the various parameters into loadings. These measurements were made at the following locations.

3.3.1.1.4 Stage Recorder, Flow Measuring Sites

1. Killian Drain at Notestine Road
2. Smith-Fry Drain at Notestine Road
3. Wertz Drain at Notestine Road
4. Gorrell Drain at Notestine Road
5. Richelderfer Drain at Notestine Road
6. Black Creek at Brush College Road
12. Black Creek at Ward Road
13. Wann Drain at Killian Road
15. Fuelling Drain at sediment basin outlet

Backwater due to flow restrictions in the lower reaches of Black Creek has on occasion caused flow measurement problems at stations 2 and 12 and to a lesser degree at other sites. Stream flow is determined by measuring stage and using a flow rating curve; however, during periods of backwater influence the stage vs. flow relationship can change unpredictably.

A deflection vane current meter was developed by the Department of Agricultural Engineering to provide improved flow determination during periods of backwater influence. The current meter measures water velocity at a fixed depth near the center of the stream. The additional flow velocity information is combined with stage data to improve the accuracy of the flow rate determination. The meter is also capable of measuring a limited range of back-flow velocities should such conditions occur.

The current meter senses flow velocity by a spring-loaded vane which is mounted perpendicular to the stream flow. A gearing mechanism provides two digital lines which indicate each 3.6 degrees of vane deflection and the direction of that movement. An analog signal proportional to vane deflection is also available. Of course, meter readings are not meaningful until the deflection vane is fully inundated. A break-away mounting bracket is used to prevent damage in the event that large floating objects strike the meter.

Current meters were installed at sampling sites 2, 6 and 12 during January, 1978.

A question posed at the beginning of the study concerned the impact of tile drainage on water quality. The following sites were utilized to collect samples to measure concentrations and loadings from tile drains.

3.3.1.1.5 Tile Drain Outfall Studies (approximate outlet locations)

R29	Richelderfer Drain at Notestine Road
B59	Black Creek at junction Darling Road and Bull Rapids
L6	Lake Drain at Bull Rapids Road
F11	Fuelling Drain Along Ward Road 1/4 mile west junction Shaffer Road
G13	200 feet east of Gorrell Drain and Notestine Road along Gorrell Drain
We6	600 feet east of Wertz Drain and Ruppert Road along Wertz Drain
SF2	Smith-Fry Drain and Notestine Road
K7	Killian Drain and St. Hwy. #101
SF26	Smith-Fry Drain and St. Hwy. #101
K65	Killian Drain and Antwerp Road
Wa2	300 feet west Wann Drain and Killian Road along Wann Drain
SF51	Smith-Fry Drain and Knouse Road
SF61	Smith-Fry Drain and Ruppert Road
SF79	Smith-Fry Drain and Springfield Center Road
We69	Wertz Drain and St. Road #37
G63	Gorrell Drain and Antwerp Road
R59	Richelderfer Drain and Hamm Road
D71	Dreisbach Drain and Antwerp Road
D122	Dreisbach Drain and Cuba Road at waterway outlet
D116	Dreisbach Drain at junction Grabill Road and Cuba Road
#20	1/4 mile east junction Gar Creek Road and St. Hwy. #101 along Miller Ditch

The effect of bank slope and mulch on ditch bank erosion was investigated systematically at two locations. These are identified and described below.

3.3.1.1.6 Ditch Bank Mulch Study Sites

1. Joe Graber Farm
Slopes -- 2:1, 3:1, 4:1
Mulch -- Straw, stone, wood chips, no mulch, aquatain, saw dust
Seeding -- Mixture tall fescue and red top

2. Dick Yerks Farm
Slopes -- 2:1, 3:1, 4:1
Mulch -- Straw, stone, wood chips, no mulch
Seeding -- Mixture tall fescue and red top

The Agricultural Research Service rainfall simulator was used to conduct several tests of the relationship between parameters such as soil type, slope, tillage, surface cover and erosion. Primary location of this work are listed below.

3.3.1.1.7 Rainulator Study Sites

1. Virgil Hirsch Farm
Nappanee silt loam; 1% slope or less
2. Virgil Hirsch Farm
Hoytville silty clay loam; 1% slopes or less

3. Dick Yerks Farm
Haskins sandy loam; 1% slope or less
4. Dennis Bennett Farm
Morley silt loam; 5% slopes
5. Graber Farm
Morley silt loam; 5% slopes

Tillage research utilizing replicated plots and several combinations of tillage was carried out at the following locations.

3.3.1.1.8 Tillage Study Sites

1. Max Woebbeking Farm -- Nappanee silty loam
2. Bill Shanebrook Farm -- Hoytville silty clay loam
3. Oliver Stieglitz Farm -- Whitaker loam
4. Roger Ehle Farm -- Rensellaer silty clay loam, Whitaker loam, Oshtemo fine sandy loam
5. Dennis Bennett Farm -- Morley silt loam
6. Bill Schaefer Farm -- Haskins loam

Automatic (PS-69) pump samplers were utilized at four locations to obtain data useful for describing variations in concentrations and loadings during a storm event. These sites are listed here.

3.3.1.1.9 Automatic Water Sampling Stations

2. Smith-Fry Drain at Notestine Road
6. Black Creek at Brush College Road
12. Black Creek at Ward Road
20. 1/4 mile east junction Gar Creek road and State Hwy. 101 along Miller Ditch (abandoned after six months due to vandalism)

An automated station capable of recording weather and stream flow data for itself and of recording and reporting data from four remote substations was installed. The locations for major elements of this system are listed here.

3.3.1.1.10 Hydrological Remote Sensoring Site

1. Black Creek at Brush College Road

3.3.1.1.11 Substations

1. Smith-Fry Drain at Notestine Road
2. Wertz Drain at Notestine Road
3. Gorrell Drain at Notestine Road
4. Richelderfer Drain at Notestine Road

3.3.1.2 SAMPLE STATIONS -- U of I

3.3.1.2.1 Fish Sample Stations

Twenty-nine sampling stations were established throughout the watershed and in nearby streams for fish studies. All (except station 14) included 100 m of stream channel. Some stations were dropped after initial studies because of special stream conditions, intermittent nature of stream, lack of fish or other reasons.

1. Killian Drain above Notestine Road
2. Smith-Fry Drain above Notestine Road
3. Wertz Drain above Notestine Road
4. Upper Gorrell Drain above Notestine Road
5. Richelderfer Drain above Notestine Road
6. Dreisbach Drain above Brush College Road
7. Lake Drain above Bull Rapids Road
8. Wertz Drain above State Highway #37
9. Dreisbach Drain above Trammel Road
10. Dreisbach Drain above State Highway #37
11. Fuelling Drain below Ward Road
12. Black Creek above Ward Road
13. Wann Drain above Killian Road
14. Maumee River at State Highway #101
15. Black Creek Downstream from entry of Smith-Fry Drain
16. Wertz Drain between Notestine Road and Black Creek
17. Black Creek immediately upstream from entry of Wertz Drain
18. Black Creek immediately below entry of Richelderfer Drain
19. Smith-Fry Drain between Indiana Highway #101 and Antwerp Road (northeast corner of intersection)
20. Dreisbach Drain above Antwerp Road
21. Hamm Interceptor at Notestine Road
22. Black Creek below entry of Richelderfer Drain
23. Maumee River at entry of Black Creek
24. Black Creek above Maumee River
25. Black Creek below Ehle Road
26. Black Creek below Darling Road
28. Black Creek below Wertz Drain
29. Black Creek immediately downstream of Smith-Fry Drain

Stations 1, 4, 5, 7, 8, 11, 14, 16, 21-25 were dropped after initial studies.

3.3.1.2.2 Water Sample Stations

University of Illinois water quality monitoring stations were established on the main stem of Black Creek, along Wertz drain, on Dreisbach Drain, and at other locations in the watershed. These are listed below and are located in Figure 8.

Dreisbach Drain

101 At Springfield Center Road, North side of road above drop structure. Grass waterway.

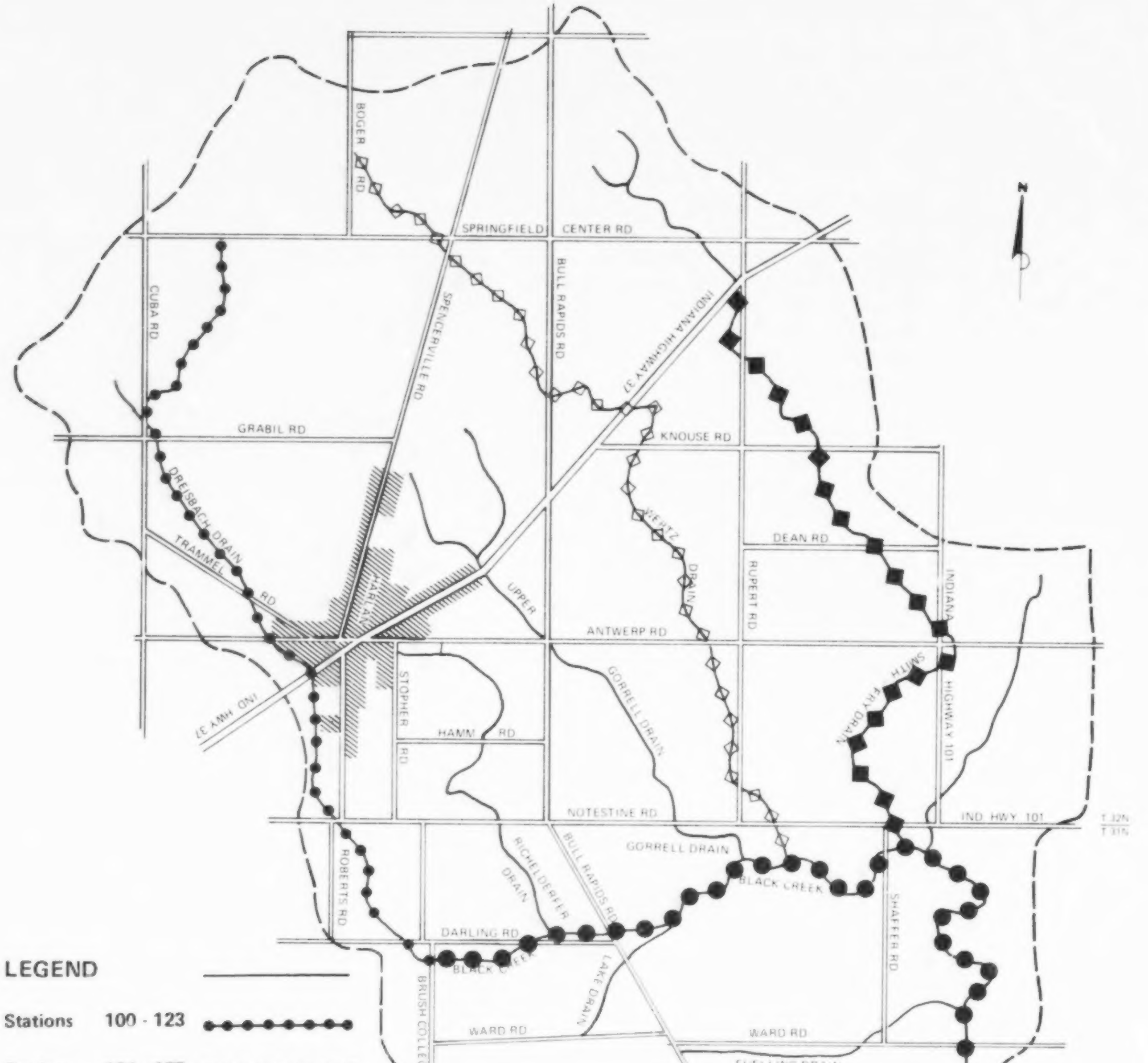
BOGER RD
SPRINGFIELD CENTER RD
CUBA RD
SPENCERVILLE RD
BULL RAPIDS RD
INDIANA HIGHWAY 37
GRABIL RD
KNOUSE RD
DREISBACH DRAIN
TRAMMEL RD
HARLAN
UPPER
WERTZ DRAIN
DEAN RD
RUPERT RD
INDIANA HIGHWAY 101
ANTWERP RD
IND HWY 37
STOPHER RD
HAMM RD
GORRELL DRAIN
SMITH FRY DRAIN
NOTESTINE RD
IND HWY 101
T 32N
T 31N
ROBERTS RD
RICHELDERFER DRAIN
BULL RAPIDS RD
GORRELL DRAIN
BLACK CREEK
SHAFFER RD
DARLING RD
BLACK CREEK
BRUSH COLLEGE RD
LAKE DRAIN
WARD RD
WARD RD
FUELLING DRAIN
R 1E
R 14E
MAUMEE RIVER
N
LEGEND
Stations 100 - 123
Stations 124 - 157
Stations 158 - 190
Stations 191 - 212

Figure 8. Illinois Monitoring Sites

102 At Cuba Road, 50 feet above bridge east side of road; lower end of grass waterway.

103 Ditch channel at Cuba Road east side of road.

104 Lower end of rip-rap at bridge west side of Cuba Road.

105 Along stream west of road at Cuba and Grabill Roads intersection; just above several "rock ledges."

106 Stream channel at above intersection; several feet above entry of water at drop structure from field to the west.

107 Water flowing over the drop structure at northwest corner of Cuba and Grabill Roads.

108 Water flowing from drain tile just south of drop structure Tile D-116.

109 Stream above bridge at Grabill Road

110 At survey flag 100 feet below swimming pool and across stream from metal tile.

111 At fence post on edge of Joe Graber farm. Upstream about 40 feet from marker flag 104+00.

Stations 110 and 111 on relatively straight channel with steep eroding bank slope.

112 Just above bridge on Joe Graber farm and short distance above "tile" outlet on west side. Downstream 30 feet from 107+00 marker flag. Channel above this station has shallow slope bank.

113 About 10 feet above rock area above Trammel Road on Dreisbach Drain. Channel above in grass with medium slope to bank.

114 40 feet upstream from bridge at Antwerp Road at middle to low end of long slow pool.

115 At lower end of rip-rap on west side of stream.

116 40 feet below sewage treatment effluent tile from trailer park.

117 10 feet north of south end of "willow" thicket along stream.

118 Just above bend in stream 3/8 mile above Notestine Road.

119 At south end of fence row but slightly above outlets of three drain tiles. Area with medium sloped bank.

120 40 feet above bridge. Bank with medium slope.

Stations 119 and 120 both on grassy channel with field border on both sides.

121 Sample at middle of fish sample station number 6B; about 150 feet above rip-rap.

122 At lower end of rip-rap.

123 Under bridge at Brush College Road.

Black Creek

124 Lower end of rip-rap below Brush College Road.

125 Fourth telephone pole downstream from bridge; end of straight channel section with grass channel and field border.

126 Above rip-rap at bend to north; somewhat meandering channel; grass channel with field border.

127 30 feet west of bridge at entry of Richelderfer Drain to Black Creek. Meandering channel with grass banks.

128 On Richelderfer Drain 40 feet above bridge on Darling Road. Grass channel with field border.

129 Downstream on Black Creek about 50 feet from entry of Richelderfer; Station 18 of fish studies.

130 40 feet above rock (rip-rap) at bend.

131 40 feet above rock (rip-rap) area just before stream turns to east.

132 20 feet above entry of Wertz Drain to Black Creek.

133 At top of riffle area in Station 28 of fish studies.

134 At bottom of riffle area in Station 28 of fish studies.

135 Discharge from surface flow from field to north.

136 Discharge from tile outlet from terraces in field to west.

137 At survey flag #395 in area with forest along both banks.

138 At lower end of forest on both banks.

139 At lower end of field on one side of stream; forest on other bank.

140 Just above Schaeffer Road bridge; heavy sewage inflow at house above Schaeffer Road.

141 Black Creek about 15 feet above entry of Smith-Fry Drain.

142 At lower end of Station 15A; woodland on west side, field on east side.

143 At lower end of rip-rap and steep erosion bank.

144 At lower end of wooded area both sides above sediment basin.

145 20 feet above bridge at sediment basin.

TECHNICAL APPROACH

146 At lower end of sediment basin.

147 About 200 meters below the sediment basin.

148 About 180 meters below station 147, and about 100 feet above flag #470 which is where the stream turns to the west.

149 At flag #477.

Comment -- Large pool at flag #480.

150 Near south end of woods but above the small drainage channel entering from the west.

Comment -- Flag #482 is about 300 to 400 feet south of edge of both sides forest.

151 Just above rock (rip-rap) area in fields.

152 At upper end of Station 12 of fish studies.

153 At lower end of Station 12 just above Ward Road.

154 At north edge of thicket area.

155 At telephone pole in field above bridge at Ehle Road -- west side.

156 Downstream from bridge at Ehle Road about halfway to river

157 Maumee River upstream from Black Creek.

Wertz Drain

158 Wertz Drain just above Boger Road; at lower end above woodlot.

159 Above Springfield Center Road. Below area of grass waterway.

160 Above Spencerville Road.

161 Overflow from drop structure at lower end of grass waterway.

162 Flow from underground pipe of waterway; east pipe.

163 Station in forest at market flag #136; moved upstream of terrace #218 outlet.

164 At fence at flag #138; some locale below first rock drop.

165 Near Bull Rapids road; flag placed on east side of stream.

166 About 400 feet downstream from Bull Rapids Road; short distance upstream from large shagbark hickory

167 Large pool at location of large tree on west bank.

168 At power line crossing.

170 Flag marks location of waterfall (at upper end); one station (169) 10 feet upstream from flag; other station (170) 30 feet downstream.

171 (Old Station 12) -- At upper end of pool about 100 meters downstream from Knouse Road near metal fence post on east bank.

172 (Old Station 11) -- In pool where stream turns to east as you move downstream. A pile of rocks and bricks are on the west bank at this point.

173 (Old Station 10) -- In pool about 200 meters upstream from bridge. No real landmarks here so distance from forest should be measured.

174 (Old Station 9) -- In pool about 10-20 meters inside woods -- even with double trunk tree laying in stream channel.

175 (Old Station 8) -- In riffle 10 meters below tree laying across stream.

176 (Old Station 7) -- In small rocky pool 5 meters upstream of large ditch on east bank -- even with triple trunk tree on west bank.

177 (Old Station 6) -- In first pool inside south end of forest; about 20 meters downstream of fallen tree across stream.

178 (Old Station 5) -- In pool in grove of trees 30-50 meters downstream of woods at point below two large cotton woods on east side of bank. Also fallen tree on field border on west side.

179 (Old Station 4) -- In pool at lower edge of grove of trees and even with north edge of trees in field 100 meters east of stream.

180 (Old Station 3B) -- In pool at lower edge of grove of trees and even with north edge of trees in field 100 meters east of stream.

181 (Old Station 3A) -- In pool about midway between large tile downstream and grove of trees upstream; even with south edge of trees in field 100 meters east of stream. Small stump on east bank.

182 (Old Station 2B) -- In pool about midway between large erosion

183 (Old Station 2A) -- In riffle area below large west bank erosion area at point where trees are not present on east bank.

184 (Old Station 1C) -- In pool, even with small tree on west side of stream below grove of trees.

185 (Old Station 1B) -- In pool, even with small tree on west side of stream below grove of trees.

186 (Old Station 1A) -- In a small pool adjacent to tree on east bank.

A more detailed map of water sample stations in Wertz Woods area is attached.

TECHNICAL APPROACH

187 100 feet downstream from fence.

188 Above bridge (some distance) above Ruppert Road.

189 Just above Notestine Road

190 Just above entry of Wertz Drain into Black Creek Smith-Fry Drain.

191 Just upstream from Highway 37 Bridge

192 At point where stream bends to east as one moves downstream.

193 Downstream about 20-30 meters from Ruppert Road.

194 Midway between Ruppert and Krouse Roads.

195 Just above Knouse Road.

196 Just above Dean Road

197 Just west of Highway 101, above Antwerp Road.

198 Just above Antwerp Road.

199 Just west of Highway 101 below Antwerp Road.

200 Just above fence at upper end of wooded area.

201 At upper end of old field thicket, pasture area, drain tile enters between 200 and 201.

202 40 yards above farm bridge crossing and just above two tile inflows; orange marker flag at site.

203 Just above eroding edge of field of east side of stream; 120 feet above forest on east side; at lower end of pool.

204 In cleaned forest area about 20 meters upstream from the tile inflow.

205 Water from large tile inflow.

206 At lower end of cleared area on west side of stream; 10 to 15 meters above fence; across from fallen tree.

207 In middle of forested, channeled section of stream, location to be determined by Dan Dudley.

208 Lower end of woodland slightly upstream from large bank slippage area.

209 Lower end of eroded bank below woodland area.

210 At lower end of straight area 25 meters above upper end of station 2 fish sample.

211 Lower end of fish sample station.

212 Entry of Smith-Fry Drain into Black Creek.

Other Stations in Watershed

213 Wertz Ditch entry to Wertz Drain. From east side between Route 37 and Knouse Road.

214 Smith-Fry Drain above bridge at Springfield-Center Road.

215 Wann Ditch above Knouse Road.

216 Small terrace just south of station 136 with drains about 20 acres.

217 Terrace area on Dreisbach Drainage located just north of Trammel Road and east of stream channel.

218 Terrace on Wertz Drain just north of station 163.

219 Terrace on Dreisbach Drain north of station 102.

220 Black Creek at downstream end of channel modification below Ehle Road.

221 Wann Ditch located just upstream of first bend above station 215.

3.3.1.3 AUTOMATIC PUMPING SAMPLERS

Automatic pumping samplers (PS-69) were installed at stations 2, 6, and 12 in the Black Creek Watershed and have been operating since February 22, 1975, March 17, 1975, and April 4, 1975, respectively. A sampler is pictured in Figure 9. The stations are located in the lower section of the watershed to allow sampler data to closely describe movement of water quality constituents from the watershed. The physical operation of the samplers has been very satisfactory (one even continued to operate while being inundated by a severe storm).

The samplers are energized only while the stage in their respective stream is above the one foot level. While energized, the samplers take a 500 ml water sample every thirty minutes with a seventy-two sample capacity (36 hours). The samples collected are analyzed for the same water quality parameters as the "grab" samples, namely, ammonium, nitrate, total nitrogen, soluble nitrogen, inorganic phosphorus, total phosphorus, soluble phosphorus, and suspended solids.

3.3.1.4 AUTOMATIC TILE SAMPLER

An automatic tile sampler has been operational since March, 1976. The operation of the tile sampling station is unique in that discrete water quality samples are collected proportionally to the tile outflow, which is continuously monitored and recorded. The time in which a sample is collected is also recorded on the flow hydrograph chart. The sampler has the capability of collecting 72, 500 ml water samples. The sampling rate is approximately 1 sample per 30 minutes at maximum flow.

Another feature of the tile sampling station is the prevention of the tile outlet from becoming inundated. This is necessary to provide reliable

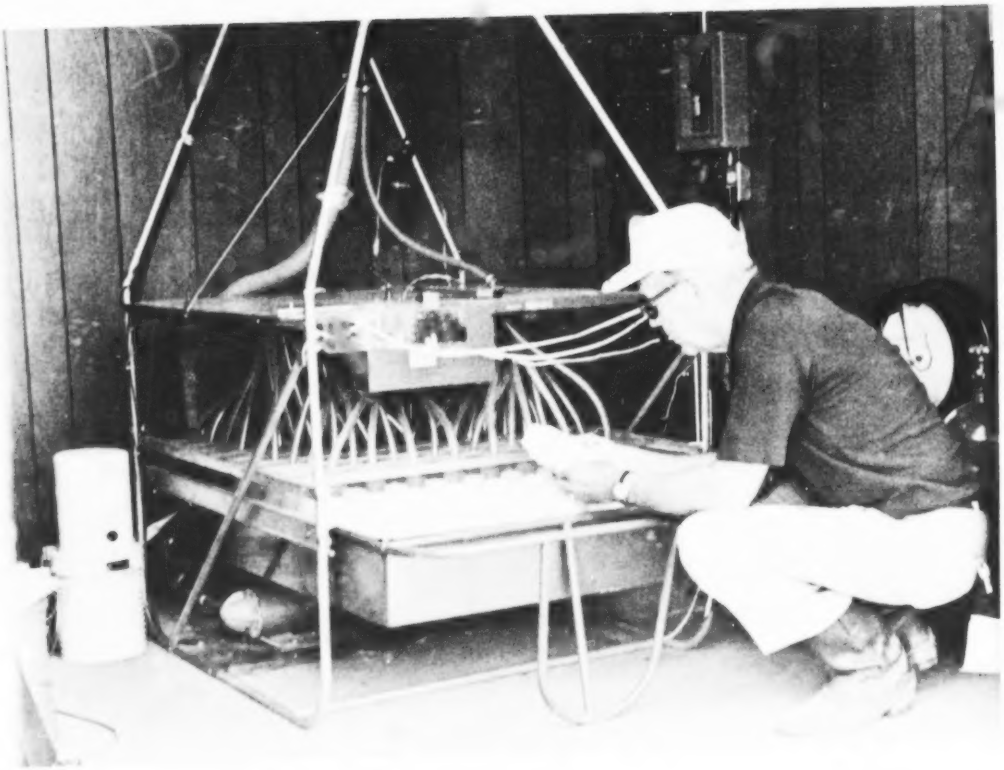

Figure 9. Automatic Pumping Sampler (PS-69)

data during storm events in which the ditch water level is above the tile outlet. Two 200 GPM pumps used in conjunction with a sump maintain a free water fall over the flow calibrated weir. The tile sampler is described in below.

3.3.2 Laboratory Analysis

3.3.2.1 PURDUE

Analysis of samples at Purdue University has been carried out according to the following procedures.

1. Suspended solids: solids in an aliquot of the water sample (250 ml) are collected on a tared Nucleopore membrane (47 mm diameter, 0.4 µm mean pore size), dried at 105 degrees C, and filter is weighed. Reported as mg suspended solids per liter of water.

2. Total nitrogen: The method of Nelson and Sommers (1975) is used to determine total N in filtered and unfiltered aliquots of water samples.

3. Ammonium -N: The method of Bremner and Keeney (1965) was used to determine ammonium -N in filtered water samples.

4. Nitrate plus nitrite -N: The method of Bremner and Keeney (1965) was used to determine (nitrite + nitrate)-N.

5. Soluble inorganic phosphorus: Reactive inorganic phosphorus was determined in filtered water samples by the method of Murphy and Riley (1962).

6. Total phosphorus: Total P in filtered and unfiltered water samples was determined by the perchloric acid digestion method of Sommers and Nelson (1972).

7. Total organic carbon: Total organic C in filtered and unfiltered water samples were determined with a Dohrman Envirotech DC-50 Carbon Analyzer.

8. Selected alkali, alkaline earth, and transition metals: Ca, Mg, Na, K, Cu, Ni, Zn, Cd, and Pb were determined in filtered water samples by atomic absorption spectrophotometry.

9. Other water parameters: temperature, dissolved oxygen, alkalinity, pH, and conductivity were determined in situ or immediately after sampling by methods described by the American Public Health Association (1971).

Calculations used in estimating constituents in water samples:

Soluble organic N - Total N(filtered) - (nitrate + nitrite + ammonium)-N
Sediment N = Total N(unfiltered) - Total N(filtered)
Soluble organic P = Total P(filtered - soluble inorganic P
Sediment P = Total P(unfiltered) - Total P(filtered)
Sediment organic C = Organic C(unfiltered - Organic C(filtered)

References

American Public Health Association, 1971. Standard Methods for the Examination of Water and Wastewater. 13th ed. American Public Health Association, Washington D.C.

Bremner, J.M. and D.R. Keeney, 1965. Stream Distillation Methods for Determination of Ammonium, Nitrate, and Nitrite. Anal. Chem. Acta. 32:485-495.

Murphy, J. and J.P. Riley, 1962. A modified single solution method for the determination of phosphate in natural water. Anal. Chem. Acta. 27:254-267.

Nelson, D.W. and L.E. Sommers, 1975. Determination of total nitrogen in natural waters. J. Environ. Qual. 4:465-468.

Sommers, L.E. and D.W. Nelson, 1972. Determination of total phosphorus in soils: A rapid perchloric acid digestion procedure. Soil Sci Soc. Amer. Proc. 36:902-904.

3.3.2.2 UNIVERSITY OF ILLINOIS

Analysis at the University of Illinois was carried out at the Illinois Natural Survey according to the procedure listed in Table 6.

TABLE 6
University of Illinois Analytic Methods

Parameters	Methods
Total Alkalinity (as CaCO3)	Metrohm Autotitrator to pH 4.6*
Total Dissolved Ionizable Solids (as NaCl)	By Calculation from Specific Conductance Table
EDTA Hardness (as CaCO3)	EDTA Colorimetric Method (Autoanalyzer)
Turbidity (JTU)	Monitek Model 150 Turbidimeter
Total Phosphorus (as P)	Stannous Chloride Method*
Soluble Orthophosphate (as P)	Ascorbic Acid Method (Autoanalyzer)*
Nitrate (as N)	Cadmium Reduction Method (Autoanalyzer)*
Nitrite (as N)	Diazotization Method (Autoanalyzer)
Ammonia (as N)	Berthelot Reaction Method (Autoanalyzer)
Organic Nitrogen (as N)	Modified Berthelot Reaction Method (Autoanalyzer)
Sulfate (as S)	Turbidimetric Method*
Residue, Total	Constant Weight Upon Drying @ 180 C, Unfiltered*

* Standard Methods

American Public Health Association, American Water Works Association,
and Water Pollution Control Federation.
1975.
Standard methods for the examination of water and wastewater,
14th ed. Washington, D. C. 1193 pp.

MERCURY - WATER

Procedure: A 50-ml aliquot of unfiltered water is treated with 10-ml of 5%

potassium sulfate and digested for 3 hours at room temperature. A 10-ml aliquot of the digested sample is transferred to the reduction vessel of the Mercury Analyzer. One ml of 5% tin chloride is added to the vessel and a 2 minute reaction time is allowed before the Hg vapor is swept through the absorption cell of the analyzer. Quantitative results are obtained by comparison with standard Hg solutions of 1, 10, and 50 ppb Hg treated in a like manner to the samples.

Equipment: Fisher Mercury Analyzer, Varian Model 485 Digital Integrator

Detection Limit: 0.2 ppm (µg Hg/ml water)

Reference: A. A. El-Awady, R. B. Miller, M. J. Carter, Analytical Chemistry 48 (1), 110-117 (1976).

WATER CATIONS - (Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Sb, Se, Si, Sn, V, Zn.)

Procedure: The sample was analyzed by emission spectrometry using a radio-frequency inductively-coupled argon plasma as the source of radiation. Standard solutions of the elements desired are used in calibrating the instrument which is controlled by a mini-computer.

Equipment: Sartorius Membrane Filter Holders, Jarrell-Ash Model 975 Plasma AtomComp

Detection limits are presented in Table 7.

TABLE 7
Detection Limits (micrograms metal/ml water)

Ag	.007 ppm	Cd	.004 ppm	Mg	.001 ppm	Se	.039 ppm
Al	.051	Co	.006	Mn	.002	Si	.030
As	.045	Cr	.007	Mo	.007	Sn	.028
B	.004	Cu	.004	Ni	.011	V	.007
Ba	.001	Fe	.020	Pb	.033	Zn	.009
Be	.001	Fe	.020	Pb	.033	Zn	.009

Reference: U. S. Environmental Protection Agency, Methods for the Analysis of Water and Wastewater, 1974.

TOTAL Hg - SEDIMENT

Procedure: A sample of sediment is centrifuged at 3,000-rpm for ten minutes and the interstitial water decanted. A 2-g sub-sample is then placed in a 250-ml Erlenmeyer flask to which 25-ml of aqua regia is added. The flask and sample are heated to boiling and boiled for two minutes. After it has cooled to room temperature, the flask has 25-ml of 5% potassium promangenate and 2-ml of 5% potassium sulfate added to it. The sample is then digested for 30 minutes in a 95 degree C water bath. The digested solution is treated with 10% ammonium hydrochloride to reduce the excess potassium promangenate. The liquid is transferred to a 100-ml volumetric flask, the residual sediment washed several times with deionized water, the washing added to the volumetric flask, and the solution diluted to volume with deionized water.

A 10-ml aliquot of the digested samples is transferred to the reduction vessel of the Mercury Analyzer. One ml of 5% tin chloride is added to the vessel, and a two minute reaction time is allowed before the Hg vapor is swept through the absorption cell of the analyzer. Quantitative results are obtained by comparison of the values obtained with the results of standard Hg solutions of 1, 10, and 50 ppb Hg treated in a like manner to the samples.

Equipment: precision 67390 Centrifuge, Blue M Model 1130A Water Bath, Fish Mercury Analyzer, Varian Model 485 Digital Integrator

Detection Limits: 2 ppb (μg Hg/g dry sediment)

Reference: I. K. Iskandar, D. R. Keeney, Environmental Science and Technology, 8 (2), 165-170 (1974).
L. W. Jacobs, D. R. Keeney, ibid, 8 (3), 267-268 (1974).

ACID EXTRACTABLE CATION - SEDIMENTS AND SOILS (Ag, Al, As, B, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Mg, Mn, Mo, Ni, Pb, Se, Si, Sn, V, Zn.)

Procedure: A 5-g representative aliquot of the sample is weighed into a 50-ml plastic centrifuge tube, and 20-ml of 0.05 N acid mixture (0.01 N sulfuric acid + 0.04 N HCl) is added. The tube is shaken mechanically for one hour and then centrifuged at 20,000-rpm for ten minutes. The supernatant is carefully decanted and analyzed by emission spectrometry using a radio-frequency inductively-coupled argon plasma as the source of radiation. Standard solutions of the elements desired are used in calibrating the instrument which is controlled by a mini-computer.

Equipment: Reciprocal shaker, Beckman Model J-21B Centrifuge, Jarrell-Ash Model 975 Plasma AtomComp

Detection Limits are presented in Table 8.

TABLE 8
Detection Limits in Micrograms Metal/Gram Dry Sediment

Ag	.03 ppm	Cd	.16 ppm	Mg	.004 ppm	Se	.16 ppm
Al	.21	Co	.02	Mn	.01	Si	.12
As	.18	Cr	.03	Mo	.03	Sn	.11
B	.02	Cu	.02	Ni	.04	V	.03
Ba	.004	Fe	.08	Pb	.13	Zn	.60
Be	.004	Hg	2.0	Sp	.19		

Reference: Perkin-Elmer Analytical Methods for Atomic Absorption Spectrophotometry, 1976.

TECHNICAL APPROACH

MERCURY - SOFT TISSUES

Procedure: The tissues are freeze-dried and pulverized so that a relatively homogeneous 0.5-g sample can be removed for analysis. The sample is weighed into a 125-ml Erlenmeyer flask, which is placed in an ice bath, and to which is added, in order, 20-ml of concentrated sulfuric acid, 10-ml of concentrated nitric acid, and 20-ml of 5% potassium promangenate. The samples are then allowed to stand 15 minutes at room temperature after which 10-ml of 5% potassium sulfate is added. The samples are then digested two hours in a 95 degree C water bath. Small amounts of solid potassium promangenate are added as needed to maintain an oxidizing environment. After digestion and cooling, the sample is diluted to volume in a 100-ml volumetric flask with deionized water.

A 10-ml aliquot of the digested sample is transferred to the reduction vessel of the Mercury Analyzer. One ml of 5% tin chloride is added to the vessel and a two minute reaction time is allowed before the Hg vapor is swept through the absorption cell of the analyzer. Quantitative results are obtained by comparison of the values obtained with the results of standard Hg solutions of 1, 10, and 50 ppb Hg treated in a like manner to the samples.

Equipment: Blue M Model 1130A Water Bath, Fisher Mercury Analyzer, Varian Model 485 Digital Integrator

Detection Limits: 4 ppb (µg Hg/g wet tissue)

Reference: W.L. Anderson, K. E. Smith, Environmental Science and Technology, 11 (1), 75-80 (1977).

Method of Analysis of Pesticides and PCB's in Water, Sediments, and Fish

Water: The volume was measured and placed in a separatory funnel. For PCB's, 100 ml of 10 percent ether in hexane was added with shaking, separated, dried over anhydrous sodium sulfate and reduced with a 3 ball Snyder column and the volume adjusted for injection into GLC. For atrazine and 245-T, the extraction was effected with three portions of 100 ml of methylene chloride which was combined, dried over sodium sulfate, reduced with a 3 ball Snyder column and exchanged with ethyl acetate for injection by flame thermionic ionization.

Sediment: Fifty grams of mixed sample were extracted by the addition of 100 ml of ethyl acetate, stirring for an hour with magnetic stirs. The ethyl acetate was decanted with rinsing, reduced in volume and dried with the addition of hexane, over anhydrous sodium sulfate. Final results were reported on a dry weight basis.

Fish: The whole fish was extracted with 100 ml acetonitrile in a blender. The acetonitrile was swirled with 10 ml hexane to remove fish oil, blown dry with nitrogen and ethyl acetate added for GLC analysis. After initial injection, they were saponified and re-extracted with hexane for confirmation of PCB's.

Samples suspected of containing 245-T were acidified by addition of a drop of hydrochloric acid before extraction and esterified before GLC injection.

Detection Systems

Lasso, Furadan, simazine, atrazine, and malathion were analyzed by flame thermionic ionization on a Varian 2100 gas chromatograph using rubidium sulfate for detection of nitrogen and phosphorus containing compounds. Column temperature 210 degrees, Port temperature 235 degrees, Nitrogen flow 15 ml per minute through a 6 foot glass column containing 3 percent OV-17 on 100-120 mesh Gas Chrom Q.

PCB's were measured under the same conditions using 3 percent OV-210 and 1.5 percent OV-17 on 100-120 mesh Gas Chrom Q in a glass column and a Ni 63 detector.

TABLE 9
Recovery of Compounds

Water and sediment:	Nitrogen containing compounds	95%+
	Phosphorus containing compounds	97.5%
	PCB's	98%
Fish:	Nitrogen containing compounds	90%
	Phosphorus containing compounds	92%
	PCB's	98%

Lower Limits of Detection

Flame thermionic ionization:	Nitrogen containing compounds	10 nanograms
	Phosphorus containing compounds	50 picograms
Electron Capture:	PCB's	100 picograms

TRACE METAL ANALYSIS

Scope: Total Cations - Cd, Fe, Zn.
Sample: Soft tissues

Procedure; A 0.5 - 1 - g sample of freeze dried tissue is weighed into a 50-ml Vycor crucible, covered, and ashed at 450 degrees C for 16-hours. After cooling, the ash is wetted with a few drops of water, and 5-ml conc. nitric acid is added. The crucible is slowly heated to dryness on a hotplate and then returned to the muffle furnace for 0.5 hours. When cool, 5-ml conc. hydrochloric acid (nitric acid if Ag is to be determined) is added and the sample heated on a hot plate to reflux under the inverted crucible cover until dissolved. The sample, crucible and cover are rinsed into a 50-ml volumetric flask and diluted to volume with deionized water. The solution is analyzed by emission spectrometry using a radio-frequency inductively-coupled argon plasma as the source of radiation. Standard solutions of the elements desired are used in calibrating the instrument which is controlled by a mini-computer.

Equipment: Muffle furnace, Hotplate, Jarrell-Ash Model 975 Plasma AtomComp

Detection Limits: ppm (μg metal/g wet tissue), Cd 0.09 ppm, Fe 1.0 ppm, Zn 0.5 ppm

Reference: K. E. Smith, Illinois Natural History Survey, in-house.

3.3.2.3 OTHER PARAMETERS

BOD -- analysis performed by Pollution Control Systems, Inc. (Laotto, Ind.) following procedures of Standard Methods (APHA 1971).

COLIFORMS -- Samples were collected in sterilized 100 ml glass bottles by immersing them at the water's surface. Testing procedures were initiated five hours or less after sample collection. The Fort Wayne Allen County Board of Health Laboratory conducted the testing. The membrane filter technique was used following Standard Methods (American Public Health Association, 1971) and the recommendations of the Millipore Company. After serial dilution of the samples, plates were inoculated. Endo Millipore, fecal MF-C Millipore and bacto KF dehydrated streptococcus broth (Difco Laboratories) were used for total coliform, fecal coliform and fecal streptococcus tests, respectively. The incubation and counting procedures outlined in Standard Methods were followed. Throughout this report the bacterial concentrations are expressed on the basis of counts per 100 ml of water.

3.3.2.4 COMPARISON OF ANALYSES

Comparisons of water quality analysis results as determined by the Purdue and Illinois Natural History Survey laboratories are shown in Figures 10 through 12 for suspended solids, ammonium N and nitrate N. Water samples were collected at 30-minute intervals during a rainstorm at three locations in the watershed. After collection, the water samples were frozen and then alternate samples were transported to the laboratories, where they were analyzed according to standard procedures used by the respective laboratory.

The concentration values for suspended solids, ammonium N, and nitrate N suggest that methods used by the two laboratories give comparable results. There was very close agreement between laboratories for nitrate N concentrations. With ammonium N, close agreement was obtained for one site, but for the other two sites, the concentrations obtained by the Purdue laboratory were higher than the concentrations obtained by the Illinois Natural History Survey Laboratory at one of these locations and lower at the other. Good agreement was obtained for suspended solid concentrations when the level was below 1400 mg/l. However, the values obtained by the Purdue laboratory were as much as 25 percent lower than those obtained by the Illinois Natural History Survey Laboratory at high suspended solid concentrations.

3.3.3 Data and Handling

The data collection procedures and equipment utilized in the Black Creek Project can best be considered in three separate categories: 1) the collection of socio-economic data, 2) data collected primarily for fishery and biological studies and 3) monitoring the effects of agricultural operations and loadings of various non-point source pollutants in the Black Creek and its tributaries. The first two categories are discussed in Sec-

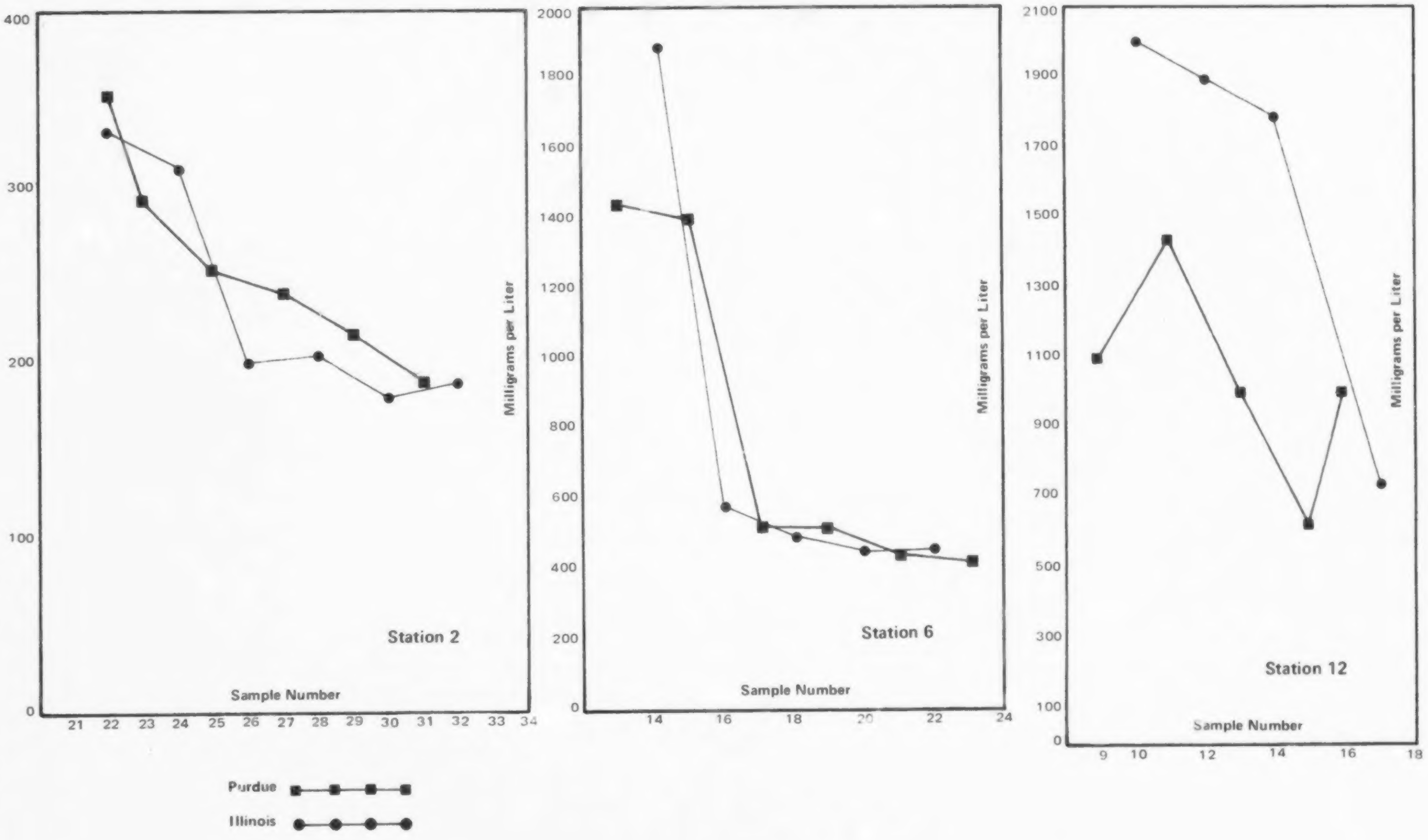

Figure 10. Comparison of Suspended Sclids

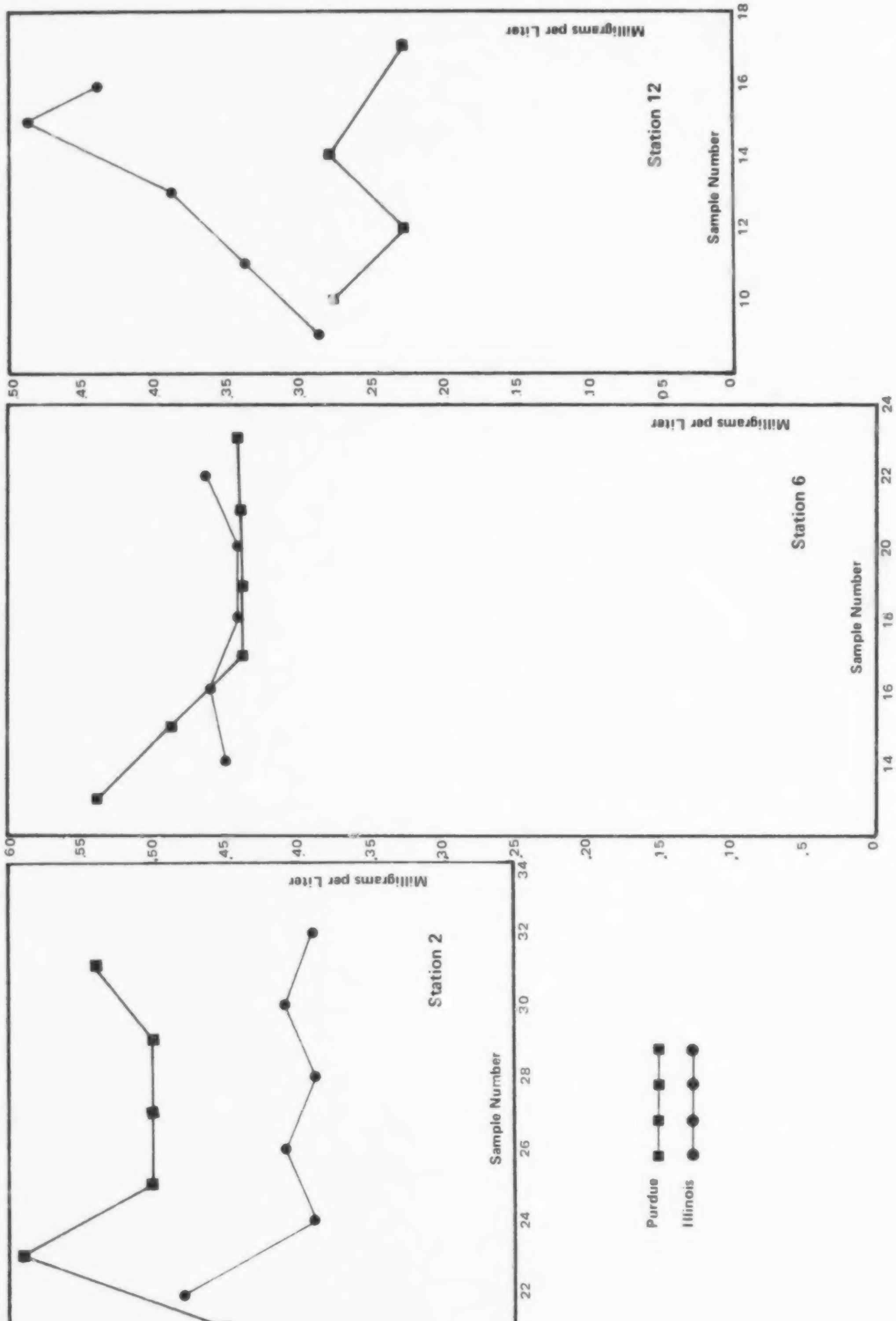

Figure 11. Comparison of Ammonium N

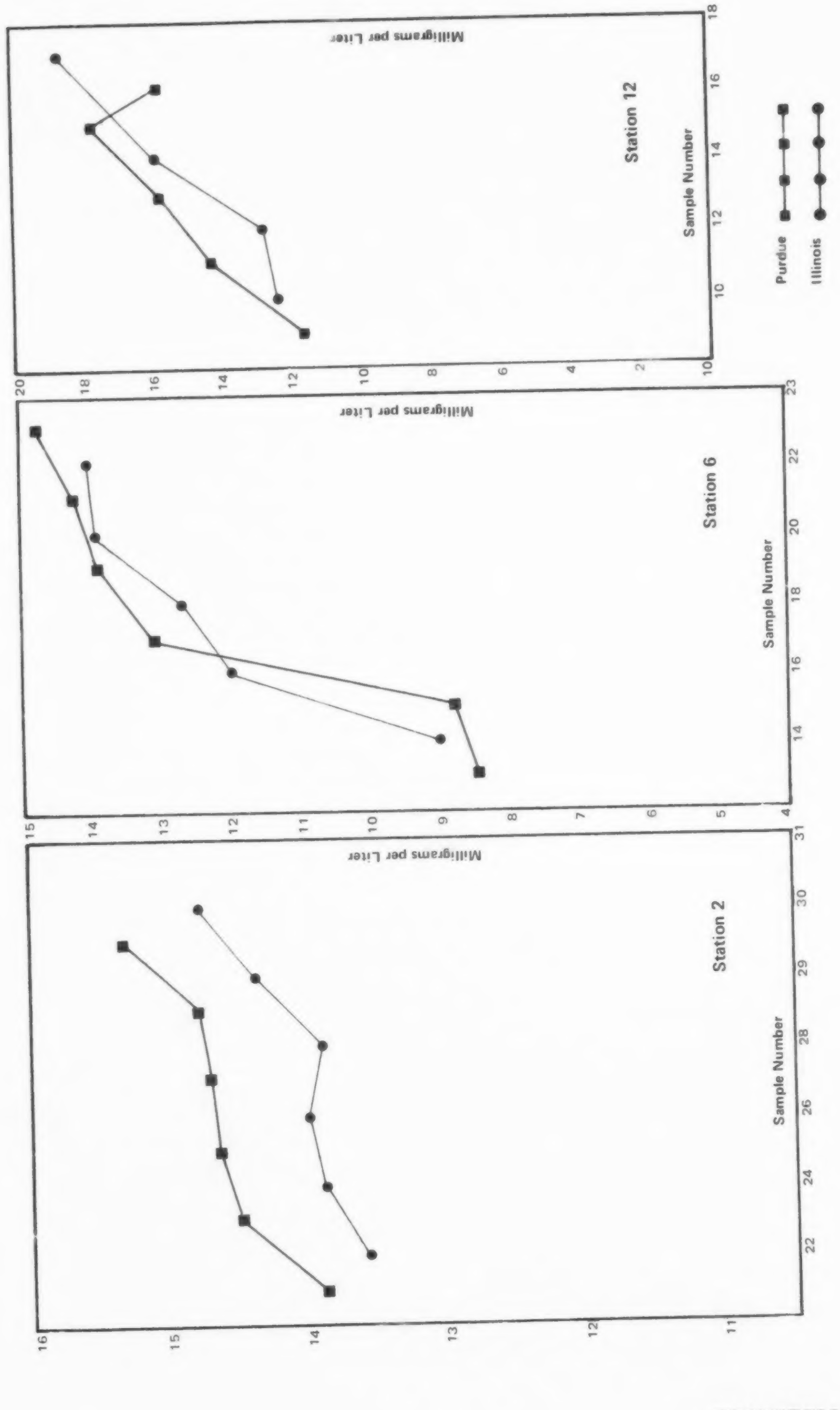

Figure 12. Comparison of Nitrate N

The concentration values for suspended solids, ammonium N, and nitrate N suggest that methods used by the two laboratories give comparable results. There was very close agreement between laboratories for nitrate N concentrations. With ammonium N, close agreement was obtained for one site, but for the other two sites, the concentrations obtained by the Purdue laboratory were higher than the concentrations obtained by the Illinois Natural History Survey Laboratory at one of these locations and lower at the other. Good agreement was obtained for suspended solid concentrations when the level was below 1400 mg/l. However, the values obtained by the Purdue laboratory were as much as 25 percent lower than those obtained by the Illinois Natural History Survey Laboratory at high suspended solid concentrations.

3.3.3 Data and Handling

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3.3.3.1 THE ALERT SYSTEM

One useful method of classifying data collection systems is according to the controller to which the basic sensors are attached. This approach allows automated systems to be divided into two broad classes: data loggers and real-time computer controlled. The primary emphasis of the following discussion is on the latter.

Traditional methods for studying natural phenomenon involve data-logging. A data-logging system is one in which the primary function is to record the data supplied from multiple sensors to a recording media. The storage is a printed copy of values, a strip chart or, in some newer units, computer readable punch tape or magnetic tape. These methods imply (1) a substantial delay between data recording and its availability to be analyzed, or (2) that media other than strip charts and printed copy be utilized to (a) reduce labor and errors associated with transcribing to computer readable media, (b) eliminate time registration errors, and (c) allow more channels of data to be recorded.

When newer technology is utilized many benefits occur. A real-time computer is one which not only collects data from an array of transducers, but has the ability to analyze that information in a sufficiently short time to effect a controlled response, dependent on the results of analyzing current conditions. Thus, the real-time computer must be able to communicate with all transducers at all times (this is called "on-line") through a communications system.

Real-time data acquisition inherently provides all the capabilities of data logging systems plus those resulting from the expanded analytical capabilities of an associated on-line computer. While real-time systems are generally more expensive, the additional costs are normally a small percentage of the total outlay for an environmental data acquisition network. In view of the substantially increased benefits, they can often be easily justified.

The most important factor which determines the success of a data collection system is the fidelity of the data collected. The fidelity of a data base refers to its ability to accurately portray the complete behavior of the system it purports to characterize. Data base fidelity is dependent upon: 1) proper positioning of adequate numbers of sensors to permit continuous inference of the complete state of the processes under study and 2) the operational reliability of all components of the data acquisition system. Selection of sensor location is highly process dependent and outside the scope of this discussion. However, the fact that operational reliability is strongly influenced by system organization, as well as transducer hardware selection, is inadequately appreciated.

Assembling a system to collect data from a dispersed network of unattended instruments which must operate over wide environmental extremes is not easy. It requires both careful selection of reliable instruments as well as proper system configuration. This involves a configuration which provides redundancy and cross-checking measurements. An on-line computer contributes to both of these areas.

First, an on-line computer affords a direct means of providing a redundant data recording system. No real-time data acquisition which is intended to maintain a continuous historical data file should solely rely on the on-line computer to record incoming data. A backup data logging capability, preferably battery powered, which requires neither the computer nor the communication link between the computer and the field instruments should be a part of the backup system. Secondly, the analytical capacity of an on-line computer makes it feasible to institute sophisticated transducer error detection schemes. In addition to the simple alarm limit approach, one can incorporate tests for rates of change on single and correlated variables. Cross checking can also be program controlled. For example, air temperature readings can be combined with net solar radiation data to yield independent estimates of soil temperatures adequate to detect a questionable operational status for a soil temperature transducer.

Since the communication link to an on-line computer is a two-way path, it is a comparatively minor task to implement operational control of field equipment which is dependent upon environmental conditions. Consider the data acquisition needs associated with monitoring nonpoint source pollution in a stream. Many of these pollutant problems are storm related and involve rapidly changing concentrations. A real-time computer, monitoring hydrometeorological conditions in a watershed, can control the activation of remote pumping water samplers to collect frequent samples during rapidly changing conditions, but infrequent samples during slowly changing conditions. Such an approach simultaneously improves the fidelity of the data base and reduces the total number of water samples which must be collected and analyzed.

An integral part of any data collection program is the "permanent" storage of data in a format suitable for subsequent intended uses. This function is virtually unchanged between real-time and off-line systems. However, the virtually instantaneous availability of current as well as historical data files with on-line systems has many ramifications for utilizing this information.

The real payoffs for real-time systems almost all are direct consequences of immediately applying the phenomenal analytical capability of a general-purpose computer to data arriving from a remote sensor network. It is the elimination of the time lag between the acquisition of data and its analysis/interpretation which makes real-time systems attractive. Of course, any benefits to be realized are totally dependent upon the ingenuity of the persons responsible for developing the computer programs which must analyze all incoming data.

3.3.3.1.1 Configuration

In July of 1976, a major amendment to the original Black Creek Project was approved. The additional activity funded under this amendment was the development of an automated data acquisition system and an associated distributed parameter hydrologic model. The subsequent development of a system designed to accomplish the Acquisition of Local Environmentally Related Trends, ALERT, was intended to accomplish two primary objectives: (1) to automate the process of collecting hydrometeorological data from the Black Creek catchment in order to reduce data transcribing delay and labor while expanding the scope of data collected and (2) to demonstrate a real-time acquisition system capable of providing a data base to permit hydrologic simulation of watershed responses concurrently with naturally occurring storm events. It should be noted that the ALERT system is a combination of both hardware (transducers, etc) and computer software.

An integral part of the second objective for ALERT involved using the computer to generate operational commands to control pumping samplers which collect periodic water quality samples during a runoff event. The availability of simultaneous data from a network of sensors dispersed over the watershed together with the predictive capabilities of the on-line computer were intended to improve the fidelity of these water samples. This improved fidelity is a result of using short sampling intervals when pollution concentrations are likely to be changing rapidly and much slower sampling rates when conditions are stable. The rapid sampling rates make possible an accurate evaluation of total quantity of pollutant in the runoff while slow rates during stable conditions reduce the number of samples collected and the cost of subsequent laboratory analyses. While the ALERT system was designed to satisfy the objectives of a specific project, the requirements were of such a nature that the resulting system is directly applicable to a large percentage of environmental data acquisition applications.

The ALERT hardware was constrained by three major requirements: battery powered operation, low cost, and field maintainability.

The system hardware must function in areas where 110 VAC line power is not available. This requirement resulted in the use of solar chargers on NICAD* batteries. This type of energy source resulted in limited power availability which restricted the amount of electronics possible at each site. Second, wherever possible CMOS# logic elements were used. CMOS logic has the attribute of using very low power when it is not active. Due to the relatively low rates of change involved in environmental monitoring a great deal of power is conserved. * NICAD is an acronym for NIckel-CADmium. NICAD batteries exhibit long shelf-life, high current capability, small size, and are rechargeable. # CMOS is an acronym for Complementary Symmetric Metal Oxide Silicon.

One objective of the project was to develop a data acquisition system which would have general applicability to other environmental monitoring applications. Therefore, it was especially desirable to develop a system of low unit cost. A remote site with a standard set of transducers (for our applications) cost on the order of $1500.00. This requirement did somewhat restrict the choice of power supplies described above and precluded reliance on commercially available complete acquisition systems. In addition, certain desirable features had to be held to a minimum. A rather large reduction in data transfer redundancy was made to cut power consumption and unit cost. Naturally, this had some adverse influence on data integrity. Since design of the remote stations, a CMOS microprocessor has become available. The designers believe that another project in this area should carefully check this possibility of having at low power consumption a very high level of intelligence (as needed to implement redundance in data transfer).

The distance between the designers and the watershed dictated that the system be constructed of modular pieces. All circuit modules plug into a mating connector. This allows field personnel with limited electronics background to change systems modules and maintain an operational status.

The configuration of the ALERT hardware as implemented is shown in Figure 13.

As in all data acquisitions systems the information begins at the (1) transducers. The ALERT hardware is based on an Incremental Increment Recording system. This system was developed by Goodspeed and Savage (1966), evaluated in detail by Langham (1971) and compared to the more widely known Time Increment Recording system by Wong, et al (1976). IIR transducers indicate whenever a fixed change occurs in current conditions, e.g., a drop in temperature of .5 degrees. This technique allows the conversion from analog to digital data at the earliest possible moment which increases data integrity, ease of transmission and results in an extremely efficient data storage format.

Each transducer reports any incremental change of conditions to its (2) remote station. A transducer may be up to 200 meters away from its remote station. A remote station then waits for permission from the central site to transmit its data. Permission to transmit occurs about once every 2 seconds. After a remote station sends the transducer data to the central site, the remote site signals the transducer that data has been sent and it

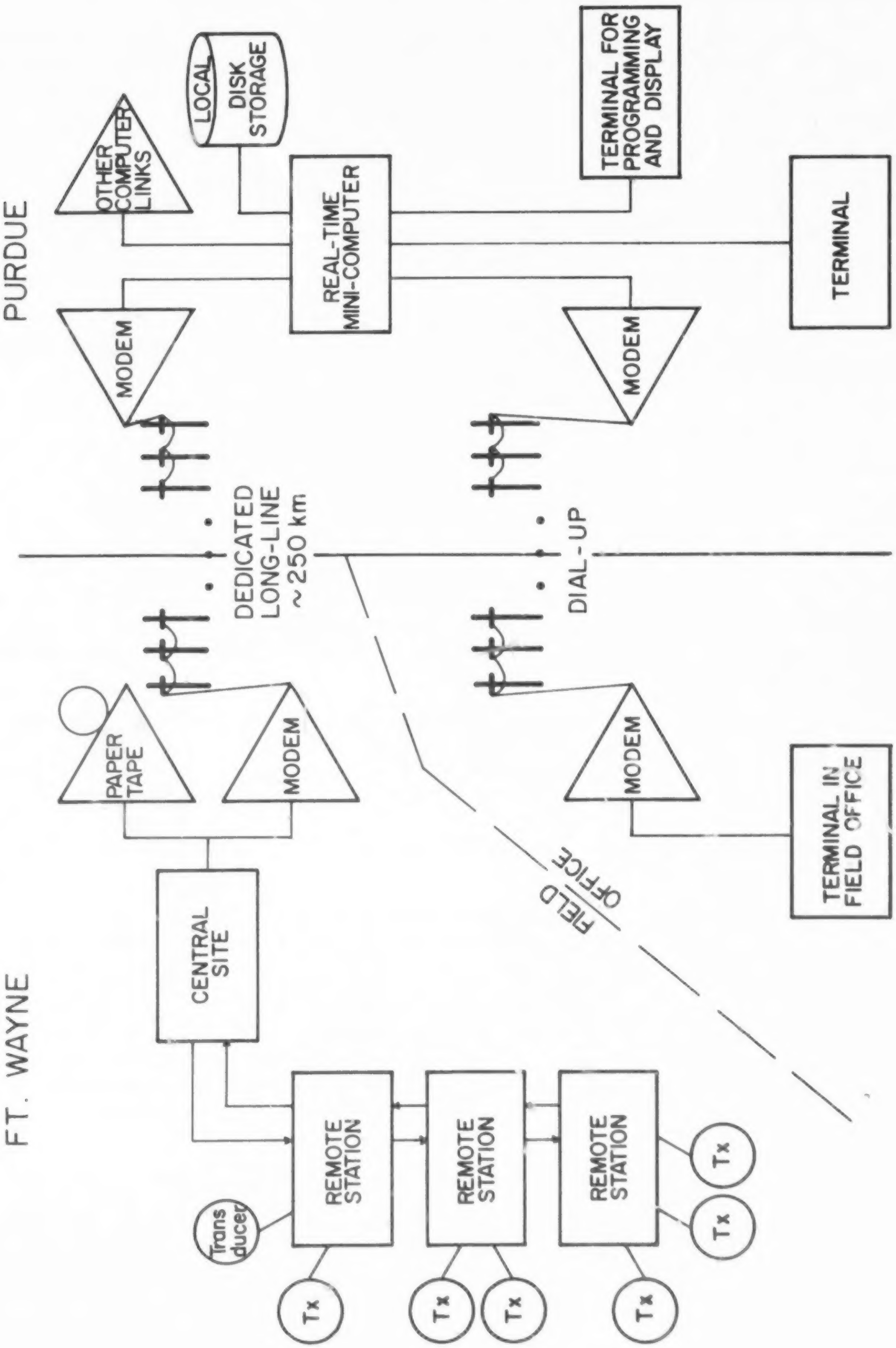
FT. WAYNE
PURDUE
Trans ducer
Tx
REMOTE STATION
REMOTE STATION
REMOTE STATION
CENTRAL SITE
PAPER TAPE
MODEM
DEDICATED LONG-LINE ~250 km
DIAL-UP
FIELD OFFICE
TERMINAL IN FIELD OFFICE
MODEM
MODEM
MODEM
REAL-TIME MINI-COMPUTER
OTHER COMPUTER LINKS
LOCAL DISK STORAGE
TERMINAL FOR PROGRAMMING AND DISPLAY
TERMINAL

Figure 13. Configuration of ALERT Hardware

is ready for further information at any time.

A remote site receives its permission to transmit data (polling) and sends data to the central site on the (3) party line. The line consists of 2 separate circuits. (3a) One circuit takes the polling information and distributes it to the remotes. (3b) The other circuit accepts data from the remotes and routes it to the central site. All remotes are connected in series with one another. This implies if one remote fails the communication link fails, but it saves an enormous amount of power the remotes could not supply due to power restrictions. The party line was a special telephone circuit that by-passed the dialing equipment in the watershed area.

Both lines terminate at the (4) central site, which is physically located at watershed Site 6. The central site performs several functions including: (4a) sending continuous polling information to all remotes which prevents two remotes from simultaneously transmitting data; (4b) monitoring the long lines (see below) and interspersing control commands with polling commands; (4c) receiving data from the remote sites and (4c,a) sending the data to a modem* which impresses the data as serial bits on the long lines and (4c,b) to a paper tape punch as a backup in case of long line failure. *MODEM is an acronym for modulator-demodulator. Operating in pairs, these devices provide a standard means of converting the voltage or currents generated and required by computers into tones suitable for transmission over telephone lines.

The (5) long lines are dedicated telephone circuits electrically separate from the party line. The long lines stretch 250 km from a modem on Black Creek Watershed to a modem in the Agricultural Engineering Department at Purdue University. The telephone circuits link the modems 24 hours a day and by-pass normal dialing equipment.

The modem at the Purdue campus connects to a (6) mini-computer with real-time software. The data from the watershed appears to come from one of up to 20 users on the computer. As data are received various software packages (inter-related programs) are executed to perform the desired functions of the system as described above. The computer also has the ability to establish communications with other systems on campus (see below). Also, the machine can answer its own telephone and connect that telephone line to a modem (see below). The real-time mini-computer has a disk storage system for storing data and programs in addition to various terminals for data display and programming.

The Black Creek installation is seen by the computer as simply one of several simultaneous users active on the system. The operating program which controls communication with the Black Creek station has four primary responsibilities: (1) assembling the incoming data into suitable files and permanent storage of these files on magnetic disk and/or tape, (2) maintenance of a dynamic file of the instantaneous level of all variables being monitored in the watershed and the operational status of all transducers, (3) providing a preliminary analysis of water stage data in order to issue feedback control commands to operate the water sampling equipment, and (4) detection of storm conditions in the watershed that indicate the need to activate a complete real-time simulation of the hydrologic behavior of the catchment. During a runoff producing storm, a simulation model can be activated which combines historical data files describing physical characteristics of the catchment with real-time, dynamically changing data concerning rainfall intensity distribution and stream stage to estimate height and times of peak flows at all points in the drainage network. If the geographical location warranted such action, the computer could be programmed, based on predicted conditions, to automatically ALERT responsible authorities in the event of impending dangerous flood levels.

The ability of the computer to answer a telephone allows a "reverse information circuit." The field office in Ft. Wayne is approximately 25 km from the watershed. Using a computer terminal and a modem, the staff can phone the real-time mini-computer at W. Lafayette. At that point the Ft. Wayne office has the ability to perform any function available on the system. This includes the display of current conditions or of archive files. This capability greatly enhances the efficiency of field personnel while it increases the overall integrity of the data base by very quickly identifying malfunctions while simultaneously eliminating unnecessary field inspections of correctly working sensors. The current status report allows quick response by field personnel to thundershower events which may occur in the catchment, but not in the vicinity of their office.

Another feature available through the software allows the real-time mini-computer to link to other computers. A linkage is available to the system which logs the most recent messages from the NOAA weather service. This service provides the most recent Ft. Wayne area forecast and Maumee River predictions, as supplied via NOAA, as a supplement to the tools available to the Ft. Wayne staff.

Operational experience with the system has been only partially successful. The primary meteorological station at Site 6, the battery operated paper tape punch, the long-lines to W. Lafayette and the on-line mini-computer have operated together very satisfactorily for over two years. The area that has involved the greatest difficulties is a low power method to couple the remote stations to the "party line". Devices that exhibit high reliability in transfer of data have also shown a low resistance to outside destruction. The destruction usually comes in the form of a lighting strike in the watershed area, although it is possible for routine telephone repair procedures in the vicinity to damage the interface boards. Interface boards, which had protection circuits for the above problems, exhibited a markedly lower reliability in transmitting the data. Techniques which utilize magnetic coupling to provide isolation between the telephone lines and the remote station hardware are currently being designed.

Further projects in this area should have the following additional goals. The first goal should be to improve on the reliability of the party line interfaces. A new product on the market has been earmarked for interface testing by the designers. The new device will hopefully raise the data transfer and destruction protection reliability far above those required. The use of HI-VHF transceivers should be incorporated to support data transmission from sites where phone service is not available or where the service is unreliable or too costly. The most extensive goal would be to increase the real-time warning/simulation phase of ALERT and increase the ability of the software to function with less operator intervention.

The hardware is of no value without a software package to support it. The ALERT software presently consists of no fewer than 18 FORTRAN programs. Commands to the mini-computer are fairly simple (although restart procedures are relatively lengthy). For example, to activate the software display of current conditions the user (at Purdue or the field office) types dcc (Display Current Conditions). The terminal then responds with a display for each transducer that informs the user of: (1) the device name; (2) current value or rate; (3) trend indicator (increasing, steady, decreasing); (4) today's high and low value or rate; (5) the time of today's high and low; and (6) a series of cross checking counters. There is an option on the dcc program to also display element (4) and (5) for yesterday, the day before, and monthly totals back 2 months on those transducers that can utilize it. Other programs allow retrieval of data, testing of phone circuits, scanning of data files for illegal data, running special statistics, and editing of data files.

The data storage format is very space conserving considering the requirements put on the data base. The data storage technique allows a report generated at any time interval (resolution of 1 second). Overall the raw data is stored as a site number, a channel number, and the time since the last data arrived. The values are stored "unformatted" (non-human readable format). Programs read the raw data and reconstruct current conditions by starting at a known point in time with known conditions (a benchmark), and stepping forward through the data. A benchmark of the conditions at the most recent midnight are kept in an easily accessible form to reduce the overhead in computing current conditions which, in the case of intelligent decision making (for control), occurs many times per day.

3.3.3.1.2 Conclusions

The collection of comprehensive environmental data is an essential requirement for rational planning of nonpoint pollution control measures and for subsequent enforcement and post-planning evaluation activities. Several examples of such activities underway in the Black Creek Study area have been described. The dramatic impact of utilizing real-time computers to collect environmental data has been outlined.

Proper transducer selection and data network configuration allow existing time-sharing computer systems to serve as real-time systems for most environmental data requirements with no additional hardware or system level software changes. This approach provides the benefits of an on-line computer with no capital outlay beyond those associated with a data logging system of greatly reduced capability. While operating costs will be slightly higher for the real-time system, these extra costs are primarily proportional to the degree of utilization of the on-line features of the system and are, therefore, subject to cost/benefit considerations and administrative control. Furthermore, many of these associated benefits are sufficient to significantly influence the economic justification of the network of field transducers required for any degree of automation of data collection procedures.

References

Goodspeed, M.J. and J.V. Savage. 1969. A multi-channel digital event-recorder for field applications. _J. Sci. Instr._ v2 pp 178-182.

Langham, E.J. 1971. New approach to hydrologic data acquisition. _Proc. Am. Soc. Civil Eng. J. Hydro. Div._ HY12:1965-78.

Wong, G.A., S.J. Mahler, J.R. Barrett, Jr. and L.F. Huggins. 1976. A systematic approach to data reduction using GASP IV. Proc. Winter Simulation Conf. PP. 403-410.

3.3.3.2 PURDUE DATA HANDLING

In the Black Creek Watershed, rainfall data was collected from up to seven recording rain gauges and water stage data was collected from up to nine pressure-actuated stage records. Water quality samples were collected both manually and mechanically.

Three pumping samplers, each capable of collecting 72 consecutive samples, are located at junctions of two primary drains into Black Creek and on Black Creek approximately one and a half miles from its confluence with the Maumee River. The pumping samplers were storm-actuated. Grab samples were taken at all stage recorder sites, or strategic locations upstream from the stage recorder sites, and at selected tile outfalls. Grab samples were collected weekly and during storm events.

Rainfall or water stage data and water quality samples have been collected since early 1973. An enormous amount of information was made available for various kind of analysis. In order to put the data into useful form for future analysis, a procedure as illustrated by Figure 14 was initiated. Raw data as represented by rainfall charts, water stage charts, grab samples, and automated pump samples were processed largely by computers and then stored to be used by researchers connected with the project and researchers outside of the project who are interested in the regional aspects of the data.

Figure 14 is a schematic diagram of data processing for the Black Creek Watershed study. Steps in this process as indicated on the figure are as follows:

Step 1: Water stage and raingage charts are read on a chart reader and the data punched on paper tape.

Step 2: Data on paper tape are read into the digital computer file.

Step 3: Rainfall data, which are accumulated inches of rainfall, are transferred into rates in cm/hr.

Step 4: Areal rainfall is calculated by taking the weighted average of the rainfall data on an area basis between adjacent sites.

Step 5: Rainfall data as well as water stage and water quality data are stored by year and by the site number.

Step 6: Water stage data are edited for comma and characters and then stored by year and by the site number as in Step 5.

Step 7: Grab sample data are verified for punching errors and corrections made.

Step 8: Grab sample data are then sorted out by time, date, and site

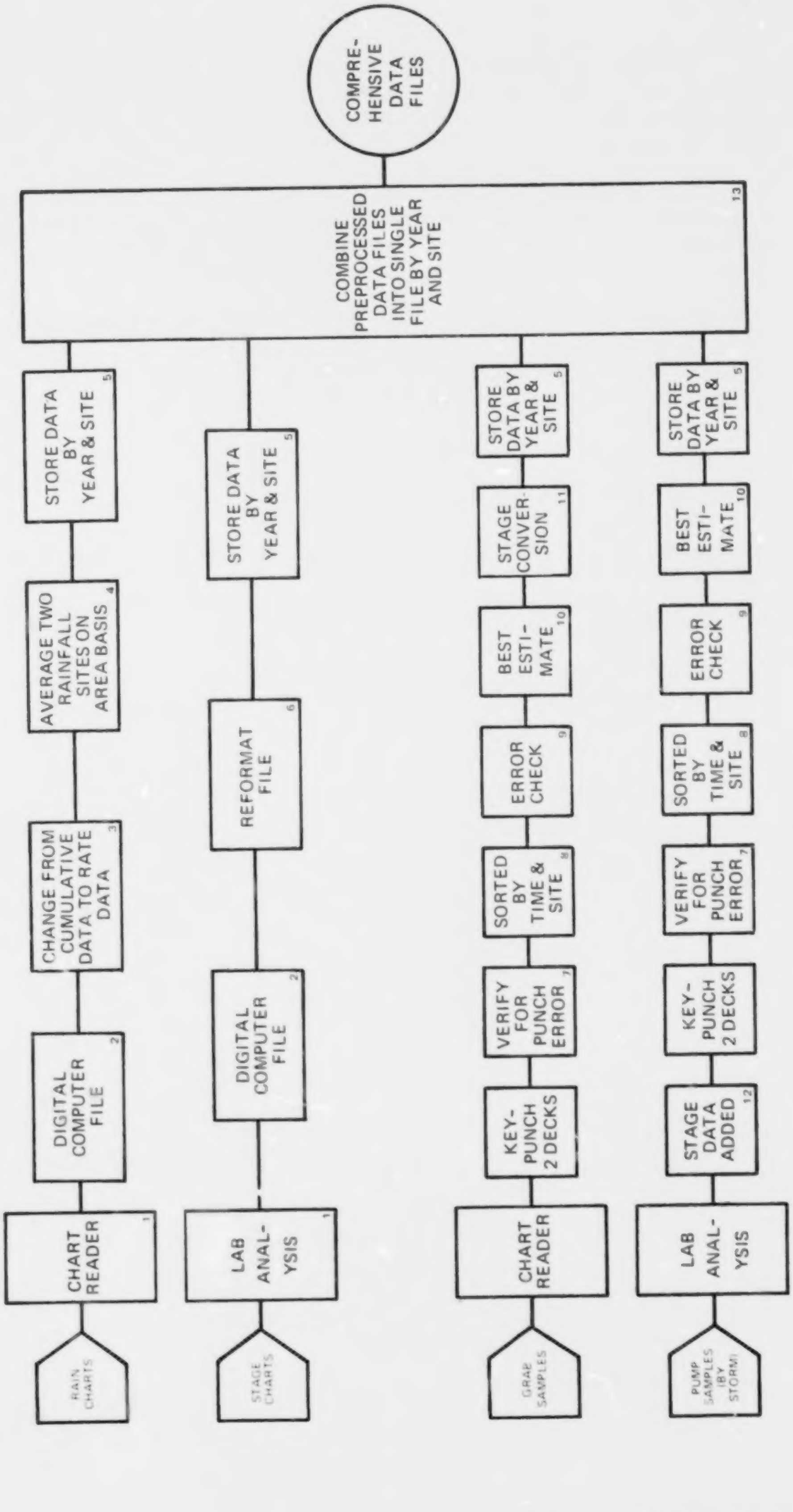
RAIN CHARTS
CHART READER 1
DIGITAL COMPUTER FILE 2
CHANGE FROM CUMULATIVE DATA TO RATE DATA 3
AVERAGE TWO RAINFALL SITES ON AREA BASIS 4
STORE DATA BY YEAR & SITE 5
STAGE CHARTS
LAB ANAL-YSIS 1
DIGITAL COMPUTER FILE 2
REFORMAT FILE 6
STORE DATA BY YEAR & SITE 5
GRAB SAMPLES
CHART READER
KEY-PUNCH 2 DECKS
VERIFY FOR PUNCH ERROR 7
SORTED BY TIME & SITE 8
ERROR CHECK 9
BEST ESTI-MATE 10
STAGE CONVER-SION 11
STORE DATA BY YEAR & SITE 5
PUMP SAMPLES (BY STORM)
LAB ANAL-YSIS
STAGE DATA ADDED 12
KEY-PUNCH 2 DECKS
VERIFY FOR PUNCH ERROR 7
SORTED BY TIME & SITE 8
ERROR CHECK 9
BEST ESTI-MATE 10
STORE DATA BY YEAR & SITE 5
COMBINE PREPROCESSED DATA FILES INTO SINGLE FILE BY YEAR AND SITE 13
COMPRE-HENSIVE DATA FILES

Figure 14. Data Processing Scheme

number.

Step 9: Grab sample data and also pump sample data are checked for errors and omissions such as poor response from a site, unrealistic dates and times, unreadable characters, abnormally high values, and bad values of N or P constituents.

Step 10: Best estimates are made for missing data or for water quality parameters, which are flagged for possible error in analysis or for wrong entries in the data log. If errors are due to faulty analysis, rules for obtaining the best estimate are:

Let soluble N = Nitrate + Ammonium, if Nitrate + Ammonium > soluble N
Let total N=soluble N, if soluble N > total N
Let soluble P=inorganic P, if inorganic P > soluble P
Let total P=soluble P, if soluble P > total P

Step 11: The distance from a benchmark to the water level is converted to depth of water for the stage record water the grab samples. The grab sample data are now stored as in Step 5.

Step 12: As in Step 11 for the grab samples, stage data are added to the pump sample file. Stage data are necessary to calculate for loadings. The pumping sample data then go through the same steps as for grab sample data and are also stored as in Step 5.

Step 13: The data files are now combined and sorted according to time and location and then placed on disk into a comprehensive data base.

STUDY RESULTS

SECTION IV

Study Results

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4.1 SIMULATED RAINFALL

4.1.1 Equipment

A portable rainfall simulator, developed by the Agricultural Research Service of USDA at Purdue University, produces artificial storms of approximately the kinetic energy of high intensity natural rainfall. The simulator was used to compare the soil loss, water loss, and infiltration rates of treatments on standard-size rectangular runoff plots.

Simulated storms may be applied to treatments being studied under any condition at any time and as often as desired throughout the year, except on tall crops and during freezing weather.

Factors well suited to tests with the simulator include: soil erodibility, length of slope, percent of slope, past erosion, crop cover at various stages of growth, rotations, fertility level, tillage practices, and residue management.

Soil and water loss evaluations by natural rainfall usually take 10 to 25 years -- yet it is often vital to have such information much sooner. The rainfall simulator frequently makes more rapid evaluations possible.

4.1.2 Objectives

Environmental Impact of Land Use on Water Quality -- A Work Plan, a plan to utilize the rainfall simulator in Black Creek watershed, was published in April of 1973. Objectives were as follows:

(a) To determine the base values for the sediment contributions of the major soil capability units in the study area.

(b) To determine runoff and sediment composition (physical and chemical) from the major soil capability units.

(c) To determine the relative importance of raindrop impact and surface runoff in detaching soil material from nearly level lake plain soil.

(d) To compare the runoff and soil erosion effects of presently used cultural practices to those conservation cultural practices recommended by the Soil Conservation Service. (Several forms of Conservation tillage compared to fall plowing, effects of crop rotations, effects of various methods of residue management, effects of winter cover, effects of over-grazing, effects of fertilizer and manure applications on cropland and pastures).

Work was carried out in all of these areas during the 1973-1976 project period. In each case, the following test storms were used:

The simulated rainfall program was started in the summer of 1973, and approximately six weeks of field testing was committed to this study each year for four years. The individual studies are outlined below.

4.1.2.1 BASE EROSION LOSSES

Values for the major soils in the watershed were obtained during the summer of 1973. Thirteen cm (5 in) of simulated rainfall were applied to fall plots under uniform test conditions on four different soils. Runoff, infiltration, sediment concentration, and total soil loss were obtained in each study.

4.1.2.2 PARTICLE SIZE IN SEDIMENT

Sediments in runoff from all four soils in the 1973 tests were analyzed for particle size distribution (five sand fractions, silt, total clay, colloidal clay, and organic matter content). These values have been compared to the values that occur in the soil in place.

4.1.2.3 SOIL LOSS AS AGGREGATES

Sediment occurring in runoff from four soils (each soil with fall plow, fall chisel, fall disk, and no tillage treatments) were analyzed for soil loss in aggregated form as constructed to that occurring as primary particles. Field and laboratory work was completed during the 1975-1976 project year.

4.1.2.4 FERTILIZER LOSS IN RUNOFF

The effects of surface applied nitrogen and phosphorus fertilizer on nutrient content of runoff were obtained under fallow plot conditions in 1973 and under four tillage systems (fall plow, fall chisel, fall disk, no tillage) in 1974 and 1975. In some instances, the tests were conducted on soybean land, and in other instances, the tests were conducted on corn land. In all instances, runoff from fertilized plots was compared to runoff from not-fertilized plots.

4.1.2.5 RAINDROP ENERGY VS. SURFACE RUNOFF

The relative importance of raindrop energy and runoff in the soil erosion process on both nearly-level and sloping soils was measured in 1973. The tests were conducted on fallow plots on four major soils in the watershed. The results were reported in the first annual report.

4.1.2.6 TILLAGE AND CROP RESIDUE

Soil Erosion was determined from four basic fall land treatments (fall plow, fall chisel, fall disk, no tillage) following both corn and soybeans during 1974, 1975, and 1976. Runoff, infiltration, and sediment concentration of the runoff were also obtained. Percent surface covered by crop residues were determined for all treatments. A portion of the data was analyzed and reported in the 1975 and 1976 progress reports.

4.1.2.7 APPLICATION OF ANIMAL WASTE

The effects of animal waste application to land, both on runoff and soil loss, as well as on water quality, were tested during the spring of 1976. Individual tests were:

(a) Spring application of liquid and solid swine waste (surface ap-

plied and incorporated) on corn stalk land.
(b) Spring application of solid swine waste on corn stalk land that had four different fall treatments (plow, chisel, disk, no tillage).
(c) Spring application of solid cattle waste to closely grazed pastures.

4.1.2.8 SOD BUFFER STRIPS, WATER QUALITY

The effects of sod buffer strips in reducing the sediment load of runoff water was a preliminary investigation and results obtained are at best an indication of the efficiency of the system.

4.1.3 Summary of Results

4.1.3.1 BASE (BARE, FALLOW CONDITION) EROSION

Runoff and soil loss values for four of the major soils in the watershed are presented in Table 10. Thirteen (13) cm of simulated rainfall were applied to fallow plots under uniform test conditions.

TABLE 10
Erosion Losses

Soil Type	% Slope	Runoff (cm)	Soil Loss (t/ha)
Haskins sandy loam	0.2	8.6	10.1
Nappanee clay loam	0.7	6.6	4.6
Hoytville silty clay	0.5	7.7	6.4
Morley clay loam	5.1	9.2	34.5

Soil erosion losses from nearly level lake plain soils under fallow conditions are low when compared to the more sloping soils in the watershed. For example, a comparison of soil losses from nearly level Nappanee and Hoytville soils versus sloping Morley soils shows the latter to be 6 to 7 times as erosive. Therefore, it can be concluded that the major soil erosion problem does not occur on the nearly level lake plain soils, but rather on the sloping, glacial till soils.

However, even on nearly level soils, significant soil loss differences can occur. Note that even though the Haskins soil had the least slope, soil loss values were approximately twice those on the Hoytville and Nappanee soils. Laboratory tests show both Hoytville and Nappanee soils are better structured than the Haskins, having major shrinkage cracks which increase infiltration. The Haskins soil was prone to surface sealing, causing increased runoff, as evidenced by the runoff data in Table 10.

Therefore, it is concluded that soil structure has a pronounced influence on soil loss -- the better the structure, the lower the soil loss.

4.1.3.2 PARTICLE SIZE DISTRIBUTION

Results show the erosion process to be highly selective with the sediment showing distinct clay enrichment and, in some instances silt fraction enrichment as well. Total clay content was often 30 percent or higher in sediment than in the original soil. Sand fraction content was appreciably lower in the sediment. These relationships occurred on both nearly level, lake plain soils and sloping glacial till soils. On nearly level soils, the clay enrichment of sediment remained somewhat constant from initial runoff until the end of the storm. On sloping soils, clay enrichment was greatest in the initial runoff, but decreased as the test storm continued.

Selective erosion, particularly clay enrichment of sediment, is occurring from cropland fields in the Black Creek Watershed. This has definite implications regarding sediment and related nutrient transport.

4.1.3.3 SOIL LOSS AS AGGREGATES

Sediment in runoff was analyzed to determine the percentage of soil loss occurring as aggregates greater than 210 microns in diameter. The results are shown in Table 11. Values presented are averages obtained during a 6.4 cm simulated rainstorm applied to fall-turn-plowed land.

TABLE 11
Soil Loss As Aggregates

Soil Type	% Aggregates in Sediment>210 micron
Haskins sandy loam	17
Nappanee clay loam	22
Hoytville silty clay	17
Morley clay loam	15

These results show that less than 20 percent of the soil transported in runoff occurs as aggregates greater than 210 microns in diameter on plowed soils. Therefore, on these soils, effective measures for reducing erosion, at least on nearly level soils, should be based on prevention of detachment and dispersion of naturally occurring aggregates by raindrops since low-velocity runoff is not capable of transporting much of the soil as large aggregates.

4.1.3.4 RAINDROP VS. SURFACE RUNOFF ENERGY

The relative importance of raindrop energy and runoff energy in the soil erosion process is shown in Table 12. These tests were conducted on fallow soils, and sediment concentrations are reported for raindrop-induced runoff and erosion vs. inflow-induced runoff and erosion.

On all four soils tested, rainfall-induced runoff contained approximately 7-12 times the sediment concentration as that found in the inflow produced runoff. These results provide further evidence that protecting the soil surface from raindrop impact is one of the most effective means of minimizing sediment concentrations in runoff.

TABLE 12
Raindrop Energy vs Surface Runoff

Soil Type	Slope	Sediment Concentration of Runoff with rain	Sediment Concentration of Runoff with inflow
	%	%	%
Haskins sandy loam	0.2	1.18	0.18
Nappanee clay loam	0.7	.98	.08
Hoytville silty clay	0.5	1.37	.14
Morley clay loam	5.1	3.81	.42

4.1.3.5 TILLAGE AND CROP RESIDUE

Soil erosion losses determined from four basic fall land treatments (fall plow, fall chisel, fall disk and no tillage) following both corn and soybeans are reported in Tables 13 and 14 12.7 cm of simulated rainfall were applied to the tillage treatments prior to seedbed preparation in the spring. The study was performed on the four major soils listed earlier, but results from only the Hoytville and Morley soils are reported below.

TABLE 13
Losses After Various Tillage Systems

(Hoytville Silty Clay 0.8% Slope)

Tillage System	Surface Cover (%) After Corn	Surface Cover (%) After Soybeans	Soil Loss (t/ha) After Corn	Soil Loss (t/ha) After Soybeans
No till (check)	78	24	1.1	7.8
Disk	77	12	.9	6.9
Chisel	57	9	1.7	9.3
Plow	4	1	4.3	5.3

From these results several significant conclusions can be drawn.

a) Soil losses are greatly reduced by those tillage systems that leave appreciable crop residues on the surface. Generally, there is an inverse relationship between surface residue cover and erosion. Particularly effective are no till (checks) and disk treatments following corn since large amounts of surface residue remain through the winter and into spring.

b) Fall chiseling following corn, although not as effective as the no till and disk, significantly reduces erosion compared to plowing. The degree of erosion control is dependent upon the amount of surface cover remaining as well as the roughness of the surface. Fall chiseling of corn land would be expected to be much more effective in reducing erosion if performed across slope rather than up and down slope (this study evaluated

TABLE 14
Losses After Various Tillage Systems

(Morley Clay Loam 4.0% Slope)

Tillage System	Surface Cover (%) After Corn	Surface Cover (%) After Soybeans	Soil Loss (t/ha) After Corn	Soil Loss (t/ha) After Soybeans
No till (check)	69	26	2.4	13.4
Disk	70	17	2.5	12.4
Chisel	25	12	15.0	30.1
Plow	7	1	21.8	40.9

up and down slope tillage).

c) None of the conservation tillage treatments are as effective following soybeans as following corn primarily because of reduced surface cover after soybeans. Chiseled soybean land can be particularly erosive when chisel marks run up and down slope.

d) The major soil losses occurred on the sloping land. Therefore, it is much more important to apply conservation tillage on the more sloping portions than the nearly level portions of the watershed to achieve significant soil erosion reductions and resultant sediment concentration in drainageways.

e) Although these tests were conducted over a relatively brief period of the erosion year, they illustrate the major influence various crop species can have on soil erosion.

f) In the only direct comparison of spring moldboard plowing and fall moldboard plowing, soil losses from 12.7 cm of simulated rain were 6.3 t/ha and 17.6 t/ha for spring and fall, respectively. It should be noted that the tests were made on a Haskins loam soil shortly after completing spring plowing.

4.1.3.6 SOD BUFFER STRIPS AND WATER QUALITY

In a preliminary investigation the influence of 50 feet of bluegrass sod in reducing sediment load of runoff water was investigated. Sediment concentration of runoff decreased from 1% to 0.46% (54% reduction) when passed over the sod. Although this study demonstrated that sediment load can be effectively reduced by sod strips, it is recognized that the effectiveness of the practice is dependent upon many factors. These would include original composition of sediment, rate and depth of plow, vigor and height of sod, and many others.

4.1.3.7 APPLICATION OF ANIMAL WASTE

Three experimental sites were used in the conduct of the study (Table 15). Experiment 1 was conducted to evaluate the effects of two forms of swine waste (liquid and solid) and two rates of solid swine waste addition

(90 and 238 t/ha) on losses of nutrients in surface runoff from corn residue covered surface. Experiment 2 was conducted to evaluate the interaction of solid swine waste application with tillage methods on losses of nutrients in surface runoff from a rolling Morley soil which was initially nearly saturated. Experiment 3 was conducted to determine the effects of solid cattle waste application rate (0, 90, and 180 t/ha) on losses of nutrients in surface runoff from an overgrazed pasture. The conditions under which the experiments were conducted are summarized in Table 15.

TABLE 15
Description of Experimental Conditions

Experiment No.	Soil Type	Tillage Used	Animal Waste Used	Rate of Waste t/ha
1	Nappanee	None (residues)	None	0
		None	Swine (liquid)	95.6
		None	Swine (solid)	90
		Disk (after waste added)	Swine (solid)	238
2	Morley	No-til	None	0
		No-til	Swine (solid)	90
		Chisel	None	0
		Chisel	Swine (solid)	90
		Disk	None	0
		Disk	Swine (solid)	90
		Fall Plow	None	0
		Fall Plow	Swine (solid)	90
3	Morley	None (pasture)	None	0
		None	Cattle (solid)	90
		None	Cattle (solid)	180

In most cases, tillage was performed on the plot area, animal wastes were applied at rates indicated in Table 15, and three standard simulated rainstorms were applied (see Section 4.1 for details of rainstorm sequence, intensity, and duration). In Experiment 1, plots treated with the high rate of solid swine waste were disked prior to application of rainstorms, and in Experiment 3, only two rainstorms were applied (total of 90 minutes of rain). The concentrations of solids and nutrients in animal wastes applied in each experiment are given in Table 16. The total amounts of nutrients added with each waste-treatment are given in Table 17. No waste-treatment added significant amounts of nitrate N because of the low nitrate content of the wastes.

Samples of surface runoff were collected, frozen, and stored at -10 degrees C until analyzed. All chemical analyses were performed by methods detailed in Section 3.3.2 Flow data from runoff plots was collected and calculated as described in Section 3.3.3 Computer techniques were used to integrate flow and concentration data to computeloadings. Average flow-weighted mean concentrations of nutrients were determined for each

TABLE 16
Nutrient Concentrations in Animal Wastes

Type Waste	Solids %	Amm.-N	Nit.-N	Org. N	Total P
		ppm (wet basis)			
Liquid swine	8.1	3165	27	2580	1370
Solid swine	39.0	5750	82	10190	7000
Solid cattle	23.4	1288	38	3535	690

TABLE 17
Amounts of Nutrients Added in Waste Applications to Three Experimental Sites

Experiment No.	Type Waste Applied	Rate Waste Applied t/ha	Nutrients Applied Amm.-N	Nit.-N	Org. N	Total P
			kg/ha			
1	Swine (liquid)	95.6	303	3	246	131
	Swine (solid)	90.0	524	8	970	730
	Swine (solid)	238	1350	18	2244	1396
2	Swine (solid)	90.0	524	8	970	730
3	Cattle (solid)	90.0	116	3	318	62
	Cattle (solid)	180.0	332	6	636	124

rainstorm and for all three rainstorms applied to each plot. All values are averages derived from data obtained from duplicate plots. Values for amounts of waste-derived nutrients lost in runoff were calculated as the difference in nutrient loss between waste-treated and control plots. Percentages of added nutrients lost in runoff were calculated by dividing amounts of waste-derived nutrients lost by amounts of nutrients added. All values for amounts of animal waste added are on a net basis. Values for concentrations of nutrients (N & P) in eroded sediment are on a moisture-free basis.

4.1.3.7.1 Experiment 1

Table 18 presents data on losses of sediment and nutrients in runoff from untilled Nappanee soil as affected by type and rate of swine waste application. On the average, waste application had little effect upon the amounts of water running off the soil or on the loss of nitrate in runoff. The loss of sediment was reduced, whereas the amounts of ammonium N soluble organic N (SON), sediment N, soluble inorganic phosphorus (SIP), soluble organic phosphorus (SOP), and sediment P were markedly increased by swine waste addition. Significantly higher losses of ammonium-N, SON, SIP, SOP, and sediment P were obtained with solid swine waste application (90 t/ha) as compared to liquid swine waste application (95.6 t/ha). This was expected due to higher amounts of nutrients added in the solid swine waste application (Table 17). Losses of soluble nutrients from plots receiving high amounts of solid swine waste (238 t/ha) disked-in were lower than plots receiving the low rate (90 t/ha) of waste. Incorporation of applied waste is apparently very significant in reducing losses of soluble nutrients. Losses of sediment-bound nutrients were similar at both application rates of solid swine waste.

The concentrations in runoff of all soluble nutrients except nitrate were greatly increased by swine waste application (Table 19). The concentrations of ammonium-N and SIP in runoff were high enough to constitute significant environmental problems. Disking-in solid swine waste lowered the concentrations of SON, SIP, and SOP in runoff as compared to runoff from undisked solid swine waste-treated plots. The concentrations of total N and P in sediment running off the plots were markedly increased by waste addition (four to ten times for N and three to sixteen times for P). The high total N and P contents of eroded sediment suggests mass movement of some waste particles as well as enrichment of eroded soil particles with waste-derived N and P.

Calculations indicate that substantial proportions of nutrients added in animal waste are lost in runoff if wastes are not incorporated (Table 20). From 34 to 44 percent of added ammonium-N, 20 to 25 percent of added organic N, and 7 to 16 percent of added total P was lost from plots receiving 95.6 and 90 t/ha of liquid and solid swine waste, respectively. Lower proportions of added nutrients were lost from plots having a high rate of solid swine waste (238 t/ha) incorporated by disking.

TABLE 18
Losses of Sediments and Nutrients in Runoff from Nappanee Scil

Tillage	Waste Application	Rainstorm	H_2O Runoff cm	NH_4^+-N	NO_3^--N	SON	Sed N	SIP	SOP	Sed P	Sediment
				kg/ha				kg/ha			
None	None	1	4.30	0.28	3.43	0.67	5.19	0.024	0.024	1.470	1859
		2	2.17	0.10	1.60	0.25	3.89	0.006	0.006	0.566	563
		3	2.44	0.08	1.70	0.07	3.46	0.005	0.009	0.444	589
		Total	8.91	0.46	6.73	0.99	12.54	0.035	0.039	2.480	3011
None	Liquid waste (95.6 t/ha)	1	4.40	87.22	3.19	22.65	26.11	11.111	2.711	5.398	1811
		2	2.14	10.88	1.41	2.09	6.78	1.246	0.486	0.685	457
		3	2.19	4.88	1.00	1.62	9.37	0.971	0.219	0.855	307
		Total	8.73	102.98	5.60	31.90	42.26	13.328	3.416	6.938	2575
None	Solid waste (90 t/ha)	1	3.83	184.82	2.12	125.28	21.49	20.306	4.165	7.646	560
		2	2.31	24.86	0.43	17.51	14.93	4.291	1.216	3.199	268
		3	2.88	21.95	0.68	14.05	14.09	4.837	1.492	3.121	223
		Total	9.03	231.64	3.23	156.84	50.51	29.434	6.873	13.966	1051
Disk	Solid waste (237.6 t/ha)	1	2.98	138.37	1.59	37.33	28.20	10.547	1.943	5.984	849
		2	2.12	21.95	0.42	11.70	13.03	2.430	1.130	2.898	412
		3	2.39	16.77	0.71	9.09	13.35	2.847	0.557	2.433	250
		Total	7.49	177.09	2.72	58.12	54.58	15.824	3.630	11.315	1511

TABLE 19
Concentrations of Solids and Nutrients from Nappanee Soil

Tillage	Waste Application	Rainstorm	Concentration in Runoff						Concentration in Sediment	
			Solids	NH+4-N	NO-3-N	SON	SIP	SON	P	N
			mg/l						mg/kg	
None	None	1	4323	0.7	8.0	1.0	0.06	0.06	2790	790
		2	2594	0.5	7.4	1.2	0.03	0.03	6910	1005
		3	2414	0.3	7.0	0.3	0.02	0.04	5870	754
		All	3379	0.5	7.6	1.1	0.04	0.04	4165	824
None	Liquid swine	1	4116	198.2	7.3	51.5	25.25	6.16	14420	2980
		2	2136	50.8	6.6	9.8	5.82	2.27	14840	1500
		3	1402	22.3	4.6	7.4	4.43	1.00	30520	2785
		All	2950	118.0	6.4	30.6	15.27	3.91	16410	2694
None	Solid swine (low)	1	1462	482.6	5.5	327.1	53.02	10.87	38375	13650
		2	1160	107.6	1.9	75.8	18.26	5.26	55709	11937
		3	774	76.2	2.4	48.8	16.80	5.18	63184	13996
		All	1164	256.5	3.6	173.7	32.60	7.01	48059	13288
Disk	Solid swine (high)	1	2849	464.3	5.3	125.3	35.39	6.52	33216	7048
		2	1943	103.5	2.0	55.5	11.46	5.33	31626	7034
		3	1946	70.2	3.0	38.9	11.91	2.33	53490	9732
		All	2017	236.4	3.6	77.7	21.13	4.85	36122	7488

TABLE 20

Proportions of Added Nutrients in Swine Waste Lost in Surface Runoff

Tillage	Waste Application	Amm.-N	Nit.-N	Org N	Total P
		Nutrients in Swine Waste Lost -------% of added lost in runoff*------			
None	Liquid	33.8	0.0	24.7	16.1
None	Solid (low)	44.1	0.0	20.0	6.5
Disk	Solid (high)	13.1	0.0	4.4	2.0

* Calculated as:

$$\frac{\text{(Nutrient from treated plot - nutrient from control plot) x 100}}{\text{Nutrient added in waste}}$$

4.1.3.7.2 Experiment 2

The conditions used in Experiment 2 (rolling Morley soil nearly saturated prior to waste application) were designed to test the effects of fall tillage practices and waste application on nutrient loss during winter and early spring situations. The data (Table 21) indicates that swine waste application reduced the amounts of runoff water and amounts of eroded sediment for all tillage treatments. However, waste application greatly increased the losses of ammonium-N, SON, sediment N, SIP, SOP, and sediment P. The amounts of sediment lost from waste-treated plots decreased in the following order of tillage method: no-till > fall plow > chisel > disk; whereas from control plots the order was: fall plow > chisel > no-till > disk. The amounts of soluble N compounds lost in runoff from waste treated plots decreased in the following order of tillage method: no-till > chisel > disk > fall plow; whereas for soluble P components the order was: chisel > fall plow > disk not equal no-till. Sediment N and P losses from waste-treated plots were highest for no-till and least for fall plow (N) and chisel (P) tillage treatments.

The solids content of surface runoff from all tillage methods was reduced by waste addition. The greatest reduction was observed with fall plow tillage (Table 22). Waste addition increased the ammonium-N, SON, SIP, and SON concentrations in runoff water. On the average, similar concentrations of ammonium-N, SON, and SOP were observed in runoff from waste-treated plots for all tillage treatments. Higher SIP concentrations in runoff from waste-treated plots were found with chisel and fall plow tillage as compared to disk or no tillage. The N and P concentrations in eroded sediment were markedly increased by waste addition for each tillage treatment. The highest enrichment of N and P in eroded sediment occurred with the disked plots where the N and P contents increased 13 and 29 times, respectively, as a result of waste addition. The high N and P concentrations in eroded solids from waste-treated plots suggest that mass movement of waste particles occurred during runoff. High BOD loadings on recurring streams are also possible under conditions of mass transport of waste solids.

The proportion of added ammonium-N lost in runoff from waste-treated plots varied from 19 percent (fall plow tillage) to 32 percent (no tillage), whereas none of the added nitrate-N was lost from any tillage treatment (Table 23). From 4.5 percent to 15.6 percent of the waste-derived or-

TABLE 21
Losses of Sediment and Nutrients From Morley Soil

Tillage	Waste Rate t/ha	Rainstorm	H_2O Runoff cm	Sediment	NH_4^+-N	NO_3^--N	SON	Sed N	SIP	SOP	Sed P
				kg/ha							
Chisel	90	1	2.86	726	109.47	1.43	64.99	23.97	16.449	7.587	4.520
		2	1.49	224	24.032	0.09	6.57	12.37	5.232	0.300	1.930
		3	2.60	330	23.15	0.17	9.11	7.19	5.752	0.281	2.555
		Total	6.95	1280	156.65	1.69	80.67	43.53	27.433	8.168	9.005
	0	1	3.81	4980	0.27	1.07	0.31	12.22	0.009	0.014	3.242
		2	2.30	2706	0.09	0.53	0.13	7.75	0.006	0.007	1.808
		3	2.58	2873	0.06	0.44	0.22	8.67	0.006	0.007	1.440
		Total	8.69	10559	0.42	2.04	0.66	28.64	0.021	0.029	6.490
Disk	90	1	2.25	347	80.07	0.50	48.12	20.68	3.121	6.397	11.489
		2	1.25	88	16.44	0.08	11.41	6.59	3.296	0.027	2.036
		3	2.34	157	20.94	0.13	11.27	8.31	2.907	1.467	3.640
		Total	5.815	592	117.45	0.71	70.80	35.58	9.324	7.891	17.165
	0	1	3.31	1092	0.05	0.34	0.11	8.34	0.023	0.014	1.685
		2	2.36	1270	0.07	0.46	0.04	4.16	0.025	0.011	0.702
		3	2.60	1236	0.07	0.34	0.06	4.47	0.030	0.010	1.185
		Total	8.27	3598	0.19	1.14	0.21	16.97	0.078	0.035	3.572
Fall Plow	90	1	2.11	909	67.07	0.78	48.57	18.78	10.438	3.453	8.212
		2	1.00	207	13.59	0.09	6.31	7.48	2.614	0.418	1.694
		3	2.01	391	17.42	0.18	8.73	8.84	4.387	0.641	1.824
		Total	5.12	1417	98.08	1.05	63.61	35.10	17.439	4.512	11.730
	0	1	5.40	11079	0.60	1.17	0.42	27.52	.009	0.020	5.789
		2	2.81	5358	0.14	0.64	0.37	10.58	.003	0.012	2.716
		3	2.97	5475	0.11	0.34	0.16	15.59	.001	0.010	2.547
		Total	11.18	21912	0.85	2.15	0.95	53.69	0.013	0.042	11.052
No-til	90	1	3.70	1324	127.62	0.80	82.85	46.66	1.888	6.989	26.105
		2	1.25	141	19.73	0.11	13.40	6.96	2.203	1.597	1.758
		3	2.14	139	20.24	0.10	11.42	5.23	4.354	0.511	2.131
		Total	7.09	1604	167.59	1.01	107.67	58.85	8.445	9.097	29.994
	0	1	4.18	780	0.12	0.53	0.22	6.60	0.007	0.013	1.795
		2	2.58	6232	0.09	0.51	0.18	3.31	0.013	0.007	0.609
		3	3.18	2092	0.06	0.48	0.04	5.15	0.014	0.010	0.490
		Total	9.94	4104	0.27	1.52	0.44	15.06	0.034	0.030	2.894

TABLE 22

Concentrations of Solids and Nutrients From Morley Soil

Tillage	Waste Rate t/ha	Rainstorm	Concentration in Runoff						Concentration in sediment	
			Solids	NH_4^+-N	NO_3^--N	SON	SIP	SOP	N	P
			-------------------------------------mg/l-------------------------------------						----------------mg/kg----------------	
Chisel	90	1	2538	383.76	5.00	227.24	57.71	26.53	33020	6230
		2	1503	161.29	0.60	44.09	35.11	2.01	55220	8620
		3	1269	89.08	0.65	35.04	22.12	1.08	21790	7740
		All	1841	225.40	2.43	116.07	39.47	11.75	34010	7035
	0	1	13071	0.71	2.81	0.81	0.02	0.04	2450	651
		2	11765	0.39	2.30	0.57	0.03	0.03	2860	668
		3	11136	0.23	1.71	0.85	0.02	0.03	3018	501
		All	12151	0.48	2.35	0.76	0.02	0.03	2712	615
Disk	90	1	1542	355.87	2.22	213.87	13.87	28.43	59600	33110
		2	704	131.52	0.64	91.28	26.37	0.22	74890	23140
		3	671	89.49	0.56	48.16	12.42	6.27	52930	23185
		All	1018	201.98	1.22	121.75	16.03	13.57	60100	28995
	0	1	3299	0.15	1.03	0.33	0.07	0.04	7637	1543
		2	5381	0.30	1.95	0.17	0.11	0.05	3276	553
		3	4754	0.27	1.31	0.23	0.12	0.04	3617	959
		All	4351	0.23	1.38	0.25	0.09	0.04	4717	993
Fall Plow	90	1	4308	317.87	3.70	230.19	49.47	16.37	20660	9034
		2	2070	135.90	0.90	63.19	26.14	4.18	36135	8184
		3	1498	86.67	0.90	43.43	21.83	3.19	29370	6060
		All	2768	191.58	2.05	124.24	34.06	8.81	24770	8280
	0	1	20517	1.11	2.17	0.78	0.02	0.04	2484	523
		2	19068	0.50	2.28	1.32	0.01	0.04	1975	507
		3	18434	0.37	1.15	0.54	0.003	0.03	2847	465
		All	19599	0.76	1.92	0.85	0.01	0.04	2450	504
No-til	90	1	3578	344.92	2.16	223.92	5.10	18.89	35240	19720
		2	1128	157.84	0.88	197.20	17.62	12.78	49360	12470
		3	577	83.98	0.42	47.39	18.07	2.12	37630	15330
		All	2262	236.38	1.43	151.86	11.91	12.83	36690	18700
		1	1866	0.29	1.27	0.53	0.02	0.03	8460	2300
		2	4775	0.35	1.98	0.70	0.05	0.03	2690	494
		3	6579	0.19	1.51	0.13	0.04	0.03	2462	234
		All	4129	0.27	1.53	0.44	0.03	0.03	3670	705

ganic N added was lost in soluble form or as components of eroded sediment. The highest percentage loss of added organic N was obtained with plots having no tillage performed. Limited percentages of waste-derived total P (3 to 6 percent) were lost in surface runoff from waste-treated plots. The highest percentage of added P lost was obtained with no-till plots and the lowest percentage was observed with fall plow tillage plots.

TABLE 23

Proportions of Nutrients Added Los in Surface Runoff From Morley Soil

Tillage	Nutrients in Waste Lost Amm.-N	 Nit.-N	 Org N	 Total P
	-------% of added lost in runoff*------			
No-til	31.9	0.0	15.6	6.1
Chisel	29.8	0.0	9.8	5.2
Disk	22.4	0.0	9.2	4.2
Fall Plow	18.6	0.0	4.5	3.1

* Calculated as:

$$\frac{(\text{Nutrient from treated peat - nutrient from control plot}) \times 100}{\text{Nutrient added in water}}$$

4.1.3.7.3 Experiment 3

Experiment 3 was conducted to evaluate the nutrient losses in surface runoff from a heavily manured, overgrazed pasture. The results (Table 24) from two rainstorms indicate that sediment losses were very low for all treatments. However, waste-treated plots had higher soil losses than control plots. This finding is likely the result of mass movement of manure particles during intense rainstorms. As compared to the previous results from the other waste experiments, the losses of all nutrient forms were low. However, amounts of ammonium-N, nitrate-N, SON, sediment N, SIP, SOP, and sediment P increased with increasing rate of waste application. These results likely are due to high infiltration of applied rainwater and the resultant low transport capacity of water running from the plots. It is particularly noteworthy that ammonium-N and SIP losses were low for all waste-treated plots.

Table 25 provides data on the average concentrations of solids and nutrients in runoff and nutrients in eroded sediment from the overgrazed pasture site. Solids and nutrient concentrations in runoff were low as compared to previous studies with waste-treated tilled soils. The concentrations of nitrogenous components were particularly low. The concentrations of nutrients in eroded sediment from control plots were higher than those from control plots of tilled soil because of extreme enrichment during selective erosion of pasture land. The N and P concentrations in eroded sediment were markedly increased by waste application (three-fold for N and two- to three-fold for P). Selective erosion of fine clay and mass movement of manure solids probably explain the high N and P content of eroded sediment.

Low percentages of added ammonium-N (1 to 29 percent), nitrate-N (2 to 4 percent), organic N (3 percent), and total P (4 percent) were lost in surface runoff from waste-treated plots (Table 26). The proportion of added nutrients lost in runoff decreased with increasing waste application

TABLE 24
Losses of Sediment and Nutrient in Runoff From Overgrazed Pasture

Cattle Waste Applied t/ha	Rain-storm	H2O Runoff cm	Sed-iment	Amm.-N	Nit.-N	SON	Sed N	SIP	SOP	Sed P
			kg/ha							
0	1	2.07	24	0.04	0.03	0.26	0.44	0.073	0.013	0.073
	2	2.29	21	0.10	0.04	0.39	0.66	0.010	0.007	0.080
	Total	4.36	45	0.14	0.07	0.65	1.10	0.083	0.020	0.153
90	1	1.61	63	1.34	0.07	2.17	3.96	1.122	0.061	0.232
	2	1.99	47	1.05	0.11	1.48	4.51	0.793	0.047	0.488
	Total	3.60	110	2.39	0.18	3.65	8.47	1.915	0.108	0.720
180	1	0.93	61	1.23	0.07	2.31	2.48	0.920	0.132	0.176
	2	2.98	103	2.54	0.11	4.32	11.50	2.232	0.108	1.327
	Total	3.91	164	3.77	0.18	6.63	13.98	3.152	0.340	1.503

TABLE 25
Concentrations of Solids and Nutrients From an Overgrazed Pasture

Cattle Waste Applied	Rain-storm	Concentration in Runoff						Concentration in Sediment	
		Solids	Amm.-N	Nit.-N	SON	SIP	SOP	N	P
		mg/l						mg/kg	
0	1	116	0.19	0.15	1.26	0.353	0.063	18330	3040
	2	92	0.44	0.18	1.70	0.044	0.031	31430	3810
	Ave.	103	0.32	0.16	1.49	0.190	0.046	24440	3400
90	1	391	8.32	0.44	13.48	6.969	0.379	62860	3680
	2	236	5.28	0.55	7.44	3.985	0.236	95960	10380
	Ave.	306	6.64	0.50	10.14	5.319	0.300	77000	6545
180	1	656	13.22	0.75	24.84	9.892	1.419	40660	2885
	2	346	8.52	0.37	14.50	7.490	0.362	111650	12880
	Ave.	419	9.64	0.46	16.96	8.061	0.870	85240	9165

rate. These findings suggest that runoff from heavily grazed or heavily manured pasture land does not represent a large threat to water quality if soil infiltration rates are reasonably high. The limited runoff coupled with trapping of waste particles by grass plants apparently resulted in low nutrient and solids loss in surface runoff.

TABLE 26

Proportions of Added Nutrients Lost in Surface Runoff From an Overgrazed Pasture

Cattle Waste Added t/ha	Nutrients in Cattle Waste Lost Amm.-N	Nit.-N	Org N	Total P
	-------% of added lost in runoff*-------			
90	1.9	3.7	3.3	4.0
180	1.1	1.8	3.0	3.8

* Calculated as:

$$\frac{(\text{Nutrient from treated peat : nutrient from control plot}) \times 100}{\text{Nutrient added in waste}}$$

4.1.3.7.4 Conclusions

1. Surface runoff losses of animal waste-derived nutrients (N and P) will be a problem if intense rainstorms occur soon (two to three days) after waste application.

2. Incorporation of applied annual waste will reduce nutrient losses in runoff.

3. Waste application tends to reduce soil loss because of mulch effect.

4. Sediment eroded from animal waste-treated areas is highly enriched with nutrients because of manure particles in transported solids.

5. Concentrations of soluble N and P compounds in runoff from waste treated areas are high enough to create water quality problems.

6. Waste application to untilled soil gave larger nutrient losses in runoff than waste application on areas receiving some fall tillage.

7. Large nutrient losses in runoff were observed where soils were nearly saturated before waste application due to low infiltration and high runoff.

8. Sediment and nutrient losses from waste-treated and untreated overgrazed pasture were low because of the rapid infiltration of applied rainwater into the pasture soil.

4.1.3.8 EVALUATION OF FERTILIZER LOSS

The rainfall simulator was used to evaluate the loss of fertilizer and native soil nitrogen and phosphorus from four soil types found in the Black Creek watershed. The characteristics of the four soils used are shown in Table 27. All plots of each soil type were fertilized with 50 lbs. phosphorus/ac (54 kg/ha) of triple superphosphate and 150 lbs. nitrogen/ac (168 kg/ha) as ammonium nitrate. Rainstorms were applied at an intensity of 2.50 in/hr (6.35cm/hr). Two rainstorms were applied to the larger plots, one of 60 minute duration and one of 30 minute duration. The small plots had one storm applied of 45 minute duration.

TABLE 27
Characteristics of Soils Used in the Investigation

	Soil Type			
Characteristic*	Haskins Loam	Nappanee	Morley Clay	Hoytville Silty Clay
Slope, %	0.1-0.3%	0.7-0.8%	4.7-5.2%	0.3-0.7%
Clay, %	12.5	29.5	33.0	43.8
Silt, %	44.5	41.5	43.5	42.0
Sand, %	43.0	28.9	23.5	14.2
Total N, ppm	1021	1557	1240	2969
Total P, ppm	363	706	366	1364
Ext. P, ppm	46	44	12	116
EPC, ppb	50	45	21	115

* Slope is average slope of experimental area; ext. P is amount of dilute acid soluble P (Bray P1) in soil.

The treatment conditions in this study are very severe and should reveal the losses of nutrients under the worst possible conditions for nutrient loss. High rates of nitrogen and phosphorus fertilizer were applied to the surface of the soil just prior to the initiation of a 2.50 in/hr (6.35 cm/hr) rainstorm. This type of situation presents the greatest potential for nutrient loss in runoff water.

The runoff losses of phosphorus and solids are shown in Table 28, and the losses of nitrogen are shown in Table 29. The losses of soil and nutrients were low from these gently sloping soils as compared with losses reported for other rainulator studies. It has been shown previously that soil losses of 9.4 and 11 tons/ac (21.38 and 24.74 tons/ha) resulted from two successive storms applied to a conventionally tilled bedford silt loam on a 8.3 percent and 12.4 percent slope. Soil losses from rainstorms applied to the soils in this study ranged from .07 (.15) for the nearly level Nappanee clay loam to .97 tons (2.18t) for the Morley clay loam soil having 5 percent slope. Soil losses were probably low because of the higher clay content and reduced slope of these soils as compared to the Bedford soil. The sediment nitrogen and phosphorus losses were lower than or equal to those found on the Bedford silt loam. Sediment phosphorus losses on the Bedford soil were 6.7 to 10 lbs/ac (7.52 to 11.25 kg/ha) as compared to .39 to 5.3 lbs/ac (.38 to 5.90 kg/ha) for soils in this study. Sediment nitrogen losses were also less for the soils representative of the Maumee River basin 1.4 to 22 lbs/ac (1.52 to 24.22 kg/ha) as compared to 19 to 26 lbs/ac (21.84 to 28.59 kg/ha) for the Bedford silt loam. Since the sediment losses from the bedford soil were high, it is logical that sediment nutrient losses should also be greater. Plowing down fertilizers on Bedford silt loam reduced the losses of soluble nitrogen and phosphorus to levels equal or lower than the four soils used in this study. The concentration of soluble inorganic phosphorus was reduced the most by incorporation; however, the concentrations of nitrate and ammonium were also reduced markedly by plowing. Even though surface application of fertilizer without incorporation increases the loss of soluble nitrogen and phosphorus, nutrient losses, when expressed as a percentage of fertilizer applied, remain quite low.

TABLE 28
Losses of Soil Phosphorus Components in Surface Runoff

Rainstorm Number	Storm Duration (min.)	Treatment	Total Runoff (tons/ha)	Solids Runoff	Soil Inorg. P	Sol. Org. P --kg/ha--	Sed. P	Sum of P Forms
				Haskins Loam				
1	60	U	305	2200	0.019	0.017	2.410	2.446
	60	F	368	2050	0.302	0.125	2.910	3.337
1	45	U	227	1250	0.017	0.011	1.340	1.368
	45	F	245	1000	0.400	0.000	2.490	2.890
2	30	U	239	1240	0.021	0.012	1.060	1.093
	30	F	264	1170	0.115	0.008	1.200	1.323
				Nappanee Clay Loam				
1	60	U	168	320	0.013	0.003	0.380	0.360
	60	F	210	415	0.140	0.015	0.002	0.728
1	45	U	172	730	0.015	0.002	0.728	0.745
	45	F	151	310	0.250	0.004	1.458	1.712
2	30	U	195	290	0.012	0.011	0.379	0.402
	30	F	251	770	0.051	0.031	0.931	0.995
				Hoytville Silty Clay				
1	60	U	253	410	0.054	0.030	0.822	0.906
	60	F	233	780	0.206	0.020	1.594	1.820
1	45	U	200	280	0.052	0.000	1.409	1.461
	45	F	162	700	0.165	0.036	1.396	1.597
2	30	U	256	680	0.049	0.011	1.378	1.438
	30	F	283	880	0.088	0.010	1.991	2.089
				Morley Clay Loam				
1	60	U	395	3940	0.004	0.012	2.713	2.729
	60	F	389	4380	0.115	0.020	5.905	6.040
1	45	U	234	1990	0.004	0.006	1.917	1.927
	45	F	203	1420	0.175	0.000	2.255	2.430
2	30	U	280	3190	0.003	0.005	2.208	2.216
	30	F	289	3700	0.056	0.001	3.337	3.394

TABLE 29
Losses of Nitrogen Components in Surface Runoff

Rainstorm Number	Storm Duration	Treatment	Amm.-N	Nit.-N	Sol. Org.N	Sed.N	Sum of N forms
			kg/ha				
			Haskins Loam				
1	60	U	0.067	0.706	0.088	5.270	6.131
	60	F	0.510	0.547	0.270	5.420	6.747
1	45	U	0.051	0.714	0.000	3.650	4.415
	45	F	0.750	0.750	0.000	2.690	4.441
2	30	U	0.091	0.091	0.248	3.026	3.539
	30	F	0.547	0.258	0.193	3.200	4.206
			Nappanee Clay Loam				
1	60	U	0.030	0.198	0.092	1.700	2.020
	60	F	0.863	0.295	0.353	4.130	5.640
1	45	U	0.880	0.298	0.000	1.520	1.906
	45	F	0.607	0.864	0.000	3.100	4.571
2	30	U	0.023	0.074	0.131	1.310	1.538
	30	F	0.810	0.732	0.000	3.670	5.212
			Hoytville Silty Clay				
1	60	U	0.054	1.708	0.000	3.850	5.612
	60	F	0.863	3.027	0.048	3.780	7.718
1	45	U	0.051	0.350	0.086	2.980	3.467
	45	F	0.607	4.930	0.000	3.920	3.467
2	30	U	0.023	0.340	0.033	3.950	4.346
	30	F	0.810	0.546	0.000	5.430	7.596
			Morley Clay Loam				
1	60	U	0.107	0.367	0.024	20.090	20.588
	60	F	1.629	0.777	0.000	24.220	26.626
1	45	U	0.029	0.159	0.169	10.620	20.588
	45	F	0.628	0.463	0.015	7.910	9.016
2	30	U	0.066	0.348	0.000	11.370	11.784
	30	F	1.407	0.725	0.266	13.320	15.718

It is evident from looking at the results that fertilizer application does lead to increased nutrient loss from soils. The increases are the greatest in the soluble nitrate, ammonium and inorganic phosphorus fractions. Sediment phosphorus also appears to increase with fertilizer addition, probably as a result of sorption of added inorganic phosphorus by the clay fraction in soil. The loss of sediment nitrogen does not seem to be markedly affected by fertilization.

The percent of the various types of nitrogen and phosphorus found in the runoff as compared to the total amounts of nitrogen and phosphorus in runoff is listed in Table 30. In unfertilized plots, the large majority of the nitrogen found in runoff is in the sediment. On the contrary, with fertilized plots the proportion of sediment nitrogen in runoff decreased as the ammonium-nitrogen and nitrate-nitrogen originating from fertilizer increased. However, the fraction of sediment nitrogen in fertilized plot runoff was at least 41 percent and, in most cases, greater then 50 percent of the total nitrogen. In unfertilized plots, almost all the phosphorus in runoff is sediment phosphorus. When plots are fertilized the percentage of total phosphorus in runoff present as sediment phosphorus decreases but stays at relatively high levels. Data from the fertilized plots reveals that at least 85 percent of the total phosphorus in runoff was in the sediment phase.

From the above data, it can be concluded that the most effective way to control loss of phosphorus and, to a lesser extent nitrogen, is to control soil erosion. Substantial decreases in the total nutrient load would have occurred if soil erosion were decreased. Most likely the amounts of soluble nitrogen and phosphorus in runoff would decrease if the fertilizer were incorporated in a way that would also minimize erosion.

The majority of soluble inorganic nitrogen and inorganic phosphorus in runoff is derived from fertilizer (Table 31). In most cases the majority of sediment nitrogen is derived from the soil. The Nappanee clay loam was an exception since the sediment nitrogen derived from fertilizer sources was quite high. This finding may be due to the high clay content of the soil which would increase the probability of large amounts of added ammonium present on the exchange sites of the eroded soil. Substantial proportion of the sediment phosphorus appears to be derived from the added fertilizer. This finding is further substantiated by the increased concentration of phosphorus in the sediment from fertilized plots as compared to sediment from unfertilized plots. The increases in sediment phosphorus and nitrogen in runoff resulting from fertilizer are apparently due to the attachment of ammonium to cation exchange sites and sorption of phosphate to the clay mineral surfaces shortly after fertilization. These nutrients are then carried from the plots as components of the sediment during erosion.

Total inorganic nitrogen removed in runoff from the two storms varied from 0.4 percent to 2.2 percent of that applied (Table 32). Losses of applied inorganic nitrogen from Haskins soils were substantially lower than the other three soils. This finding may have been due to the high infiltration rate in Haskins soil because of higher amounts of sand and lower clay content than other solids, thus permitting ammonium and nitrate to be moved deeper into the soil making it less susceptible to runoff. The amount of fertilizer nitrogen lost in all forms varied from 0.8 percent to 5.9 percent of that added (Table 32). The losses of added nitrogen from Haskins soil again were much lower than other soils which seems to indicate clay content of the soil may be the difference since the fertilizer nitrogen lost in the sediment phase was probably largely in the form of ammonium on the cation exchange sites.

The percentages of soluble inorganic phosphorus removal by runoff water varied from 0.3 percent to 0.7 percent of that added, and the amount of added phosphorus lost in all forms in runoff varied from 2.0 percent to 8.0 percent (Table 32). The losses of fertilizer phosphorus were larger than nitrogen losses as compared to the amounts of fertilizer nitrogen and phosphorus applied. The greater losses of applied phosphorus are apparently from the phosphate sorbed on soil surfaces since the largest amount of phosphorus in runoff is carried by the sediment. The quantities of fertilizer nutrients lost in runoff from the four soils do not represent significant monetary losses to the farmer. The nutrient losses are low considering the severity of the experimental conditions. The incorporation of the fertilizer would have likely substantially reduced losses.

The average concentrations of sediment phosphorus and extractable sediment phosphorus in runoff increased as a result of fertilization (Table

TABLE 30
Percentage distribution of Nitrogen and Phosphorus

Rainstorm Number	Storm Duration (min.)	Treatment	% of Total N in Runoff as:				% of Total P in Runoff as:		
			NH+4-N	NO-3-N	Sol. Org.N	Sed.N	Soil Inorg.P	Sol. Org.P	Sed.P
			Haskins Loam						
1	60	U	1.1	11.5	1.4	86.0	0.8	0.7	98.5
	60	F	7.6	8.1	4.0	80.3	9.1	3.8	87.2
1	45	U	1.1	16.2	0.0	82.7	1.3	0.8	98.0
	45	F	16.9	22.5	0.0	60.6	13.8	0.0	86.2
2	30	U	2.6	4.9	7.0	85.5	1.9	1.1	97.2
	30	F	13.0	6.1	4.6	76.1	8.7	0.6	90.7
			Nappanee Clay Loam						
1	60	U	1.5	9.8	4.5	84.2	3.2	0.8	96.0
	60	F	15.3	5.2	6.3	73.2	13.5	1.4	85.1
1	45	U	4.6	15.6	0.0	79.7	2.0	0.3	97.7
	45	F	13.2	18.9	0.0	67.8	14.6	0.2	85.2
2	30	U	1.5	4.8	8.5	94.9	3.0	2.7	94.3
	30	F	15.5	14.0	0.0	70.4	5.1	1.3	93.6
			Hoytville Silty Clay						
1	60	U	1.0	30.4	0.0	68.6	6.0	3.3	90.7
	60	F	11.2	39.2	0.6	49.0	11.3	1.1	87.6
1	45	U	1.5	10.1	2.5	86.0	3.6	0.0	96.4
	45	F	6.4	52.1	0.0	41.5	10.3	2.2	87.4
2	30	U	0.5	7.8	0.8	90.9	3.6	0.8	95.8
	30	F	10.7	7.2	0.0	71.5	4.2	0.5	95.3
			Morley Clay Loam						
1	60	U	0.5	1.8	0.1	97.6	0.1	0.4	99.4
	60	F	6.1	2.9	0.0	91.0	1.9	0.3	97.8
1	45	U	0.3	1.4	1.5	96.7	0.2	0.3	99.5
	45	F	7.0	5.1	0.2	87.7	7.2	0.0	92.8
2	30	U	0.6	3.0	0.0	96.5	0.1	0.2	99.6
	30	F	9.0	4.6	1.7	84.7	1.6	0.0	98.3

TABLE 31
Percentage Nutrients

Soil Type	Rainstorm Number	Form of N in Runoff			Form of P in Runoff		
		Sol. Inorg.N	Sed.N	Sum of All N Forms	Sol. Inorg.P	Sed.P	Sum of All P Forms
		% of N Derived from Fertilizer			% of P Derived from Fertilizer		
Haskins Loam	1	26.9	2.8	9.1	93.7	17.2	26.7
	2	67.1	5.4	15.8	81.7	11.7	17.4
Nappanee Clay Loam	1	80.3	58.8	64.2	90.7	75.0	61.9
	2	93.7	64.3	70.5	76.5	59.3	59.6
Hoytville Silty Loam	1	54.7	0.0	27.3	73.8	48.5	50.2
	2	73.2	27.3	42.8	44.3	30.8	31.2
Morley Clay Loam	1	80.3	17.1	22.7	96.5	54.1	54.8
	2	80.7	14.7	25.0	94.6	33.8	34.7

* Calculated by subtracting the nutrient loss from the untreated plot from that of the fertilized plot, dividing the difference by the nutrient loss from the fertilized plot, and multiplying the resultant value by 100.

TABLE 32
Added Fertilizer Nitrogen and Phosphorus Lost in Runoff

		Added N lost in runoff as:		Added P lost in runoff as:	
Soil Type	Rainstorm Number	Sol. Inorg.N	All N Forms	Sol. Inorg.P	All P Forms
		--% of added N--		--% of added P--	
Haskins Loam	1	0.2	0.4	0.5	1.6
	2	0.2	0.4	0.2	0.4
	Total	0.4	0.8	0.7	2.0
Nappanee Clay Loam	1	0.6	2.1	0.2	1.1
	2	0.9	2.1	0.1	1.1
	Total	1.5	4.2	0.3	2.2
Hoytville Silty Clay	1	1.3	1.3	0.3	1.6
	2	0.6	1.9	0.1	1.2
	Total	1.9	3.2	0.4	2.8
Morley Clay Loam	1	1.2	3.6	0.2	5.9
	2	1.0	2.3	0.1	2.1
	Total	2.2	5.9	0.3	8.0

* Percent of added nutrients lost in runoff was calculated by subtracting the nutrient loss from untreated plots from that of the fertilized plot, dividing the difference by the amount of nutrient added, and multiplying the resultant value by 100.

33). Addition of superphosphate decreased the proportion of total phosphorus in runoff present as sediment phosphorus from 96.6 percent to 91.8 percent. On the average, the total phosphorus content of the sediment increased 269 ppm, and the extractable phosphorus content of the sediment increased 97 ppm as a result of fertilization. Superphosphate addition increased the proportion of sediment phosphorus which was extractable with the Bray P1 solution from 20.6 percent to 25.2 percent suggesting that a higher percentage of added phosphorus associated with the sediment was extractable than native phosphorus associated with the sediment. The finding that in excess of 90 percent of the total phosphorus in runoff is sediment phosphorus agrees with previous work and suggests that control of soil erosion can greatly reduce the levels of total phosphorus in surface runoff.

The concentration of sediment nitrogen in runoff was not markedly affected by fertilization although the amount of sediment exchangeable ammonium increased as a result of ammonium nitrate addition. The proportion of total nitrogen in runoff present as sediment nitrogen decreased from 86 percent to 71 percent as a result of fertilization. The fact that sediment nitrogen makes up the bulk of the nitrogen in runoff suggests that control of soil erosion can greatly reduce the total amounts of nitrogen in runoff although the more available soluble nitrogen components would still be present. Fertilization increased the average Kjeldahl nitrogen content of the sediment about 280 ppm and the exchangeable ammonium content about 81 ppm. The proportion of Kjeldahl nitrogen in the sediment present as exchangeable ammonium increased from 1.2 percent to 5 percent with fertilization.

The soluble organic carbon content of runoff averaged 19.6 mg/l for unfertilized plots and 28.3 mg/l for fertilized plots. The values are somewhat higher than the soluble organic carbon contents of streams and

TABLE 33
Effect of Fertilization

Effect of Fertilization on the Phosphorus, Nitrogen and Carbon Composition of Sediment in Runoff from Four Soils and Subjected to Simulated Rainstorms

Soil Type	Treat-ment*	Rain storm	Sol. P	Ext. Sed.P	Sed. EPC	Sed. Total N	Sed. exc.NH4-N	Sed. Org.C
			ppm	ppm	ppb P	ppm	ppm	%
Haskins	U	1	530	76 (14.7)	28	1330	46 (3.5)	0.53
		2	454	65 (14.3)	35	1710	47 (2.7)	1.13
		3	520	94 (18.1)	30	1590	60 (3.3)	1.00
	F	1	643	213 (33.1)	455	1750	105 (6.0)	1.18
		2	685	150 (21.9)	180	1610	116 (7.2)	1.00
		3	661	178 (26.9)	175	1620	73 (4.5)	2.64
Nappanee	U	1	267	113 (42.3)	74	790	0 (0.0)	3.48
		2	422	153 (36.0)	44	2570	0 (0.0)	3.89
		3	258	127 (49.2)	44	1040	0 (0.0)	3.76
	F	1	547	199 (36.4)	300	1840	125 (6.8)	2.50
		2	707	167 (23.6)	136	1830	89 (4.9)	5.11
		3	828	155 (18.7)	136	1590	104 (6.5)	2.64
Morley	U	1	553	25 (4.5)	4	1860	26 (1.4)	1.45
		2	513	31 (6.0)	10	1650	28 (1.7)	1.18
		3	477	34 (7.1)	9	1590	20 (1.3)	1.04
	F	1	665	196 (29.5)	104	2070	95 (4.6)	1.68
		2	697	146 (20.9)	54	1890	100 (4.8)	1.38
		3	823	161 (19.6)	48	2030	80 (3.9)	2.35
Hoytville	U	1	1230	231 (18.8)	15	2350	0 (0.0)	2.13
		2	1355	243 (18.3)	86	3190	0 (0.0)	5.11
		3	1202	217 (13.1)	94	3160	0 (0.0)	3.78
	F	1	1375	368 (26.8)	284	2870	118 (4.1)	5.81
		2	1466	320 (21.8)	138	3570	114 (3.2)	3.81
		3	1414	331 (23.4)	138	3490	103 (2.9)	2.90
Average	U		607	118 (20.6)	39	1903	19 (1.2)	2.37
	F		876	215 (25.2)	179	2180	102 (5.0)	2.62

* U-unfertilized; F-fertilized

Values in parenthesis are extractable P as a % of sediment total P and exchangeable ammonium as a % of sediment total N.

rivers, which are usually about 10 mg/l. The average sediment organic carbon concentration in runoff was about 200 mg/l, thus the organic carbon to Kjeldahl nitrogen ratio (C/N) for surface runoff was approximately 11. Soils normally have a C/N ratio of 9 to 12, so it can be seen that sediment carbon and sediment nitrogen are being eroded in roughly the same proportion that they occur in the soil.

There was a strong relationship between the solids content of runoff and the sediment phosphorus concentration in the runoff. A similar relationship was observed between solids and the sediment nitrogen content of runoff. These findings suggest that the solids content of surface runoff provides a good indication of the relative amounts of sediment nitrogen and phosphorus present in runoff. It may be possible to obtain a semiquantitative estimate of the sediment nitrogen and phosphorus content of runoff based upon solids content in a given watershed if most soils in the watershed are similar.

The solids content was also significantly correlated with the soluble organic phosphorus concentration, the soluble organic carbon content, and the exchangeable ammonium concentration in the sediment. Thus, it appears that the solids content of surface runoff from these soils is a key factor in determining the concentrations of certain forms of nitrogen, phosphorus, and carbon in runoff. However, solids content may not always be related to sediment nitrogen and phosphorus content since soil type, slope of the soil, natural fertility and other soil associated factors can affect the composition of the sediments inducing variability. Therefore, the nitrogen and phosphorus concentration in sediment may change as related to the original soil because of selective enrichment by smaller size fractions, especially clay. When prediction of nutrient content of sediments is made, these factors need to be considered.

Clay content of the runoff was related to solids, soluble organic phosphorus, sediment total phosphorus and organic carbon in the sediment. It appears that the clay fraction carried a large portion of these nutrients contained in the runoff. Clay particles especially the related amorphous material, have a high affinity for phosphate ions and organic molecules.

A very high correlation coefficient (r=0.91) was obtained for the relationship between the soluble inorganic phosphorus concentration in runoff and the equilibrium phosphorus concentration (EPC) of runoff sediment. It appears that the concentration of soluble inorganic phosphorus in runoff may be accurately estimated by determining the EPC of the sediment. It is interesting to note that the relationship between soluble inorganic phosphorus and sediment EPC was observed even when results from several soils were combined and when the solids content of runoff varied from 0.17 percent 2.74. These findings suggest that the relationship between the sediment EPC and the soluble inorganic phosphorus concentration in water is similar for different soil types.

The original soil EPC, when compared to soluble inorganic phosphorus concentration of the runoff from unfertilized plots, resulted in a correlation coefficient of 0.81, which indicates under certain conditions the original soil EPC may be useful in predicting the soluble inorganic phosphorus in runoff. The nature of the equilibrium between the soil and solution makes it possible for the soil to buffer solution phosphorus. Soil, when associated with solutions of low phosphorus status, may desorb phosphorus whereas under conditions of high concentrations of solution phosphorus the soil may sorb phosphorus. If the composition of the runoff is known, predictions can be made to assess the contribution of sediment phosphorus in runoff to the phosphorus status of lakes and streams.

Sediment phosphorus in runoff was related to the concentration of soluble phosphorus in runoff and to the concentration of soluble organic carbon and sediment organic carbon in runoff. As expected the concentration of extractable phosphorus in the sediment was directly related to the concentration of total phosphorus in the sediment. The concentration of extractable phosphorus in sediment was also related to sediment EPC. This finding suggests that the EPC technique and the Bray P-1 extraction procedure measure a similar fraction of soil phosphorus which determines the concentration of orthophosphate in equilibrium solutions. It has been observed that EPC measures the buffering capacity of a soil for phosphate, whereas Bray P-1 extraction measures the phosphate potential of the soil.

The soluble ammonium nitrogen concentration in runoff was related to the exchangeable ammonium nitrogen concentration in runoff and to the exchangeable ammonium nitrogen content of the sediment. This finding suggests that an equilibrium exists between the soluble ammonium in runoff and the exchangeable ammonium present on solids in runoff. Thus, it may be possible to predict one of these forms of ammonium in runoff if the other form is known. Soluble organic nitrogen in runoff is related to the concentration of sediment nitrogen in runoff and to the concentration of exchangeable ammonium in the sediment. It appears likely that a given proportion of organic nitrogen in these soils is solubilized during runoff events and therefore soils containing high organic nitrogen contents have runoff higher in soluble organic nitrogen than soils containing low concentrations of organic matter.

The four soils used in the study were separated into their sand, silt, and clay fractions for chemical analysis. The fractionation procedure gave fractions which represented 94.3 percent of the weight of the original sample. A higher recovery could have been achieved if the large volumes of suspended clay could have been air-dried in a short period of time. The freezing process made recovery much faster since a major portion of the supernatant could be decanted.

The results of the chemical analysis of the soil constituents and the original soils are presented in Table 34. The analyses of samples for total phosphorus, total nitrogen, and extractable phosphorus all indicate that the highest concentrations of nitrogen and phosphorus in soil are associated with the clay fraction.

Phosphorus adsorption on clays has been related to the presence of amorphous oxides and hydrous oxides or iron and aluminum. The presence of iron oxide and hydrous oxide coatings on clay mineral surfaces has been reported. Such coatings, along with greater surface area, may explain the fact that a large proportion of the total phosphorus in the soil is associated with the clay fractions. Since silt and clay are, in many cases, preferentially eroded, higher losses of sediment nitrogen and phosphorus would be expected than if the soil were eroded in mass. This observation has led to the use of enrichment ratios where the concentration of sand, silt, and clay in the particulate phase of surface runoff is compared to concentrations in the soil. Previous researchers have observed increases in clay content of eroded materials. For a soil containing 16 percent to 18 percent clay, clay percentage in the eroded material increased from 25 percent to 60 percent as runoff diminished from 2.7 inches to .01 inches (70 mm to

TABLE 34
Analysis of Soil Size Fraction

Soil Type	Fraction	Percent of Soil	Total N	Total P	Extractable P*	EPC**
			------------u /g		------------	--ng/ml--
Haskins	whole soil	100.0	1021	364	46	
Loam	sand	43.0	166	168	29	5
	silt	44.5	710	240	36	3
	clay	12.4	4406	1135	155	28
Morley	whole soil	100.0	1240	366	12.4	
Clay Loam	sand	23.5	225	90	10.5	0
	silt	43.4	835	127	10.5	0
	clay	33.0	2165	739	16.1	0
Hoytville	whole soil	100.0	2969	1241	117	
Silty Clay	sand	14.2	424	704	49	0
	silt	42.1	1794	756	102	7
	clay	43.7	4466	1364	166	44
Nappanee	whole soil	100.0	1557	706	44	
Clay Loam	sand	28.9	182	399	21	1
	silt	41.6	972	335	34	2
	clay	29.5	3231	1109	75	9

* Bray P, (Jackson, 1970).

** EPC - equilibrium phosphorus concentration (Taylor and Kunishi, 1971).

0.25 mm) of runoff per hour. Runoff from storms of lesser intensity may carry as much sediment phosphorus as intense storms due to greater enrichment during low runoff.

If selective erosion occurs, the potential for enriching water with nutrients is increased because the concentration of nutrients in the clay fraction is much higher than the whole soil. It is apparent that selective erosion occurred in these soils because the nitrogen and phosphorus concentration of the sediment from unfertilized plots are higher than those of the whole soil and in some cases higher than the concentration in the clay fraction of the soil. This finding suggests that the fine clay particles are being eroded preferentially and could be a potential source of nitrogen and phosphorus to the solution due to the higher nutrient concentration of the fine clay.

Phosphorus adsorption isotherm relations were determined for the three factions of each soil. The isotherms indicate clay has the greatest ability to buffer the soluble phosphorus concentration. The clays, when subjected to concentrations of soluble orthophosphate greater than the EPC, will sorb phosphorus from solution. Clay in stream and lake systems can serve as a phosphate sink during periods of high phosphorus concentration. Even though clay may holding the largest fraction of phosphorus in streams and lakes it also has the ability to maintain the concentration of phosphorus in solution at levels lower than in runoff which enters the water. The concentration maintained is most likely dependent upon the EPC of the eroded material and the EPC of the material present on the stream bank and lake bottoms.

4.1.3.9 CONCLUSIONS

Fertilizers increase the soluble nitrate-nitrogen, ammonium nitrogen and orthophosphate-phosphorus content of runoff. These losses are small (none greater than 8 percent) as compared to the amount of fertilizer nutrient added to the soil. The soluble inorganic nitrogen and phosphorus in runoff are readily available for algal growth; and therefore, reduction of the concentration of nutrients in runoff is desirable.

Sediments contain the majority of nitrogen and phosphorus in runoff. Sediment nitrogen and phosphorus are not immediately available to aquatic plants but these forms may serve as potential nutrient sources. The greatest portion of nitrogen and phosphorus associated with sediment appears to be in the clay fraction. Soils susceptible to selective erosion may yield sediment which contain more nitrogen and phosphorus than the original soil since clay and silt percentages of sediment generally increase relative to the soil during erosion. The best approach for reducing nutrient loss from cropland appears to be erosion and runoff control.

Practices such as fertilizer incorporation are important as indicated by this study and previous investigations. Conservation tillage methods need to be evaluated with respect to control of erosion and runoff and suitability to present day farming practices.

The findings of this study allow one to make certain inferences about the composition of runoff from soils of the Upper Maumee River watershed. It appears that the solids and clay content of the runoff are the most important parameters in controlling the concentrations of several forms of nitrogen and phosphorus in runoff. The data suggests that control of soil erosion and proper incorporation of fertilizers (to prevent mass movement of fertilizer in runoff water) can greatly reduce the concentrations of nutrients in runoff from the soils studied.

The concentration of soluble inorganic phosphorus in runoff (possibly the most important single parameter in eutrophication) can be estimated by measurement of the EPC or the extractable phosphorus content of eroded material. The EPC value of unfertilized soil or soils in which phosphorus fertilizers have been incorporated can be used to estimate the soluble inorganic phosphorus concentration in runoff. These relationships should be very useful in development of models for prediction of nutrient loss in the Maumee River watershed.

The concentration of soluble ammonium in runoff can be estimated from the exchangeable ammonium content of the runoff sediment. It also appears likely that the exchangeable ammonium content of the soil is related to the soluble ammonium concentration in runoff. The concentration of nitrate in the runoff was not related to any runoff properties which were measured. This is to be expected in that nitrate is water soluble and is not associated with the solid phase of the soil. This finding suggests that development o a model for loss of nitrate in runoff water will be very difficult because nitrate losses are dependent upon a large number of hydrologic and soil factors.

References

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4.2 BANK STABILITY STUDIES

Two study areas were selected to determine the effect of slope and mulching materials on the revegetation of the stream banks and of the effects of the mulching materials in controlling erosion during the revegetation. Site 1 on the upper end of the Dreisbach Drain (on the Joe Graber farm) was installed in September-October, 1973. Site 2 on the Wertz Drain between Notestine Road and Black Creek (on the Dick Yerks farm) was installed in April, 1974. Three slopes, 2:1, 3:1, and 4:1 were used at each site. Mulch materials of stone, straw, and wood chips along with a check or no-mulch were used on both locations. In addition, aquatain and sawdust were used on the Joe Graber farm.

The final evaluation on May 2, 1975, showed that all mulches were effective in controlling erosion and in helping to establish cover. There was no consistent difference in the mulch material effectiveness with the exception of the stone mulch. Stone appeared to be slightly superior in controlling erosion resulting from high water, and resulted in as good or better grass cover than other mulch materials. In May of 1974 both the wood chip and straw mulch materials were washed away during high water flow in the Wertz Drain. While there is not a totally consistent advantage of one mulch material over the other, all mulches improve the establishment of the grass and help control erosion during the establishment period.

The 3:1 slopes appeared to be slightly better than either the 2:1 or the 4:1 slopes. This can vary with local conditions. For example, on the Graber farm the 3:1 slopes are far superior to the others but this is complicated by the fact that there was more good soil on the 3:1 slopes than on any of the other two slopes. In fact, a year and a half after the establishment and planting of grass, the 2:1 and 4:1 slopes on the Graber farm still showed evidences of low fertility. Grass cover helped control erosion in all cases.

Bank stability studies were a part of original plan of work. To determine if a correlation might exist between bank cover, particularly trees vs. grass, and bank stability. The reported data of the SCS study in Black Creek has been reviewed. While this data shows a strong correlation between soil type and bank erosion it is not possible to relate erosion and cover in the published data.

Three sites were initially selected for studies to determine if the channels were agrading or degrading. Two of the sites have since been reconstructed and revegetated. Observation of the third site (Wertz Drain south of the woods and north of Antwerp Road) indicates that the channel is relatively stable with little or no accumulation or loss.

High water flow during May of 1974 deposited one to two inches of silt and sand on the mulch study plots on the Wertz Drain. Other evidences of such deposition during high flows has been observed throughout the watershed. There is also evidence of continued cutting of some of the channels where velocities of flow are high. This seems to be especially true where velocities are high during normal to low flow such as occurs on the mulch study area on the Dreisbach Drain. Observations of channel scour are in agreement with stability studies which showed that many of the lower bank and channel bottoms were unstable for existing flow and slope conditions throughout many areas of the Maumee Basin.

Soil mechanics studies have identified several locations where channel bottoms are potentially unstable. The most likely reason for instability is excess channel slope and a less resistant soil material in the profile near the channel bottom. It is evident that if a channel bottom degrades even stable banks eventually must become unstable.

Four sites were selected for study of channel bottom stability. One, on the Joe Graber farm, was known to have lowered 30 to 60 cm (1 to 2 feet) following revegetation of the banks. In this area, small rock drop structures were installed in 1975.

The Black Creek channel at Notestine Road was surveyed for a distance of 30 m (150 ft.) upstream and 65 m (200 ft.) downstream from the bridge. This is an area where rock was used for channel training. It is also an area where soil mechanics studies indicated a potentially unstable channel at flood flow. This channel was shown to be unstable because of the soil material in the channel bottom and also the slope, 0.25 percent. This 115 m (350 ft.) degraded approximately 42 cm (1.4 ft.) between May of 1974 and August of 1976. The channel has considerable grass and other water type vegetation in the bottom.

Another site on the Gorrell drain along Notestine Road for a distance of 165 m (500 ft.) downstream from the monitoring site shows the ditch bottom to be almost identical with the original. This section has an average slope of 0.2 m per 100 m (0.20 percent). This is the smallest slope of any of the four sites studied.

Wertz drain between Notestine Road and the main channel of the Black Creek, a distance of approximately 305 m (1000 ft.), was a site of the bank slope-mulch studies. This channel reach has an average slope of 0.4 percent (0.4 meters per 100). Earlier observations had indicated that the channel bottom was eroding in several sites. The survey conducted in August of 1976 showed that with the exception of a section about 200 meters below the Notestine Road all of the channel had eroded. For the first 160 m (500 ft.) an average lowering of approximately 30 cm (1 ft.) occurred between March of 1974 and August of 1976. The last 70 meters (200 ft.) above the main Black Creek channel eroded approximately 45 cm (1.5 ft.). There are several areas in this section where erosion of the channel bottom has caused the top of the banks to slip into the channel.

These survey results plus other observations indicate that there are a number of sections throughout the Black Creek watershed where channel bottom erosion is producing unstable bank conditions.

Survey of Streambank Erosion

As a part of the International Joint Commission PLUARG studies, streambank erosion is being surveyed under the direction of a Mr. W. F. Mildner of the Soil Conservation Service. These studies are generally made on a statistical sampling basis, but because of the intensity of the Black Creek Study and the size of the basin, a complete survey was made in this particular watershed.

The study was conducted in the summer of 1975 and the data has recently been made available to the author by Mr. Mildner. The survey covered 29.3 miles on stream for a total bank miles of 58.6. The following measurements are listed in bank miles. The drainage density was determined to be 1.56 miles of channel per square mile. It was determined that there are 7.2 eroding bank miles producing approximately 400 tons of sediment per year. It was estimated that only 6.3 miles of simple treatment and 0.9 miles of armoring would solve this problem. At the present time there are 18.4 miles of simple treatment and 1.7 miles of armoring in the watershed.

There does not appear to be any correlation of the bank erosion with use of the adjacent land or with whether or not the banks are fenced. It is interesting to note that over 80 percent of the total tons of streambank erosion are produced by two soil types, Eel 59.4 percent and Shoals 25.1 percent. Yet the same soils account for only 18.7 and 7.3 percent respectively of the total miles of streambanks.

While this survey shows a relatively small amount of sediment produced by streambank erosion, nevertheless at the site of occurrence the erosion may be quite severe. Often the eroding sections can be controlled with a comparatively small amount of simple treatment. The need to control bank erosion emphasizes a need for a good maintenance program in any plan to reduce sedimentation.

4.3 SEDIMENT BASINS

The sediment pond, a small sediment basin, was constructed on the Virgil Hirsch farm in the fall of 1973. It filled to overflowing in November of that year. It serves a drainage area of 185 ha (460 acres). The soil types are Hoytville and Nappanee. The land slopes are generally less than one-half per cent. Sediment depositions were determined by fathometer and by probing. Sediment was examined for determination of particle size. Sediment samples for laboratory analysis were collected.

Sediment deposits were found to be uniform is depth throughout the pond area with an average accumulation of 6 cm (0.2 ft.). Particle sizes were uniform, being primarily in the clay and silt fractions, with a small amount of fine sand.

Laboratory analysis of the samples confirmed that the sediment is a silty clay texture. The range of the sample analysis were as follows:

Silt	52.1 -- 63.9%
Clay	31.9 -- 42.0%
Sand	4.2 -- 5.9%

The sediment pond accumulated 1880 cu m (2400 cu yd.) of sediment.

Assuming a dry weight of 857 kg per cu meter (55 pounds per cubic foot) this amounts to an average of 2.8 ton per ha per year (1.2 tons of sediment per acre per year). However, this figure cannot be projected as a long term average because of two factors:

1) The area immediately to the north of the pond site was in a transition stage and was very subject to erosion until the conservation practices on it were completed in 1975. Thus, this area may have contributed above a normal amount of sediment in this three year period. There has also been some construction activity on the west end of the pond site.

2) In May of 1975, a nearly 100-year frequency storm was received. This storm produced the highest runoff volume and sediment concentrations yet measured at many of the stations. It produced between 1/3 and 1/2 of the 1975 annual sediment transport at some of the measuring stations.

The Desilting Basin on the main stream of the Black Creek was constructed in September of 1974 and was first surveyed on July 30, 1975. A second survey was conducted July 7, 1976. Sediment samples were collected from this basin for particle size determination.

The first survey covering a period of approximately nine months showed an accumulation of 770 cubic meters (980 cubic yards) of material. The second survey showed an additional accumulation of 416 cu meters (530 cubic yards) in approximately a one year additional time. Sediment sample analysis is shown in Table 35. This table shows only the per cent sand by size fraction and does not include the finer silt and clay fractions. It is only at stations 460 and 461 where less than one-half of the sediment accumulated was in the sand size fraction.

TABLE 35

Percent Sand and Sizes in Desilting Basin Deposits at Stations Listed

	Size Range in mm						Total %*
Station	>2	2to1	1to.5	.5to.25	.25to.1	.1to.05	Sand
457+000	26.58	11.68	17.36	27.46	6.67	1.48	91.23
458+000	7.94	5.15	11.52	46.07	16.43	2.44	89.55
459+000	.85	1.09	2.41	14.88	33.01	13.93	66.17
460+000	.38	.46	.19	1.28	17.02	21.24	40.57
461+000	0	0	.13	.88	13.59	21.08	35.68

* Percent sand is based on total dry oven weight of sample.

This would indicate that much of the material being trapped by this desilting basin is bed-load. To date, no evidence has been seen of additional scour of the channel immediately below the desilting basin. The first 50 meters (150 ft.) of this basin is nearly full. If it continues to trap material at the present rate, it will have to be cleaned out to remain effective.

4.4 MICROBIOLOGICAL STUDIES

Microbiological studies were conducted on grab samples collected at stations throughout the watershed.

To discover the variability associated with grab sampling and analysis of the water samples, triplicate samples were collected from station 312 on April 31, 1977. Agreement between the samples was good (see Table 36). However, the estimated standard deviations are, in many cases, as large as the differences between stations (except where septic tank effluent greatly elevated the counts). Due to this level of variability and an incomplete data record at many stations, it was decided not to examine the data from individual stations. Instead, the general patterns of bacterial contamination in the Black Creek watershed were defined by grouping similar stations together. The results, during conditions of low stream discharge, are presented in Section 4.4.1.

TABLE 36
Bacterial Counts From Surface Water Station 312, May 31, 1977

	Total coliform	Fecal coliform	Fecal streptococcus
	2,700	400	100
	1,600	700	100
	1,700	100	200
Mean	2,000	400	133
Standard Deviation	608	300	64

4.4.1 Bacterial Counts at Low Flow

On five of the six sampling dates, the stream discharge in Black Creek was considered to be low (see Table 37). This distinction was not made on the basis of an arbitrary numerical discharge rate but rather on the presence or absence of surface runoff from agricultural land. At low stream discharge there was no surface runoff, while at high stream discharge there was substantial surface runoff.

A total of 65 observations from 20 surface water stations are available to estimate the bacterial counts expected in the Black Creek watershed given normal conditions of low stream discharge. Table 38 summarizes this information. The mean values are unrealistically high because of unusual environmental conditions, such as nearby septic tank outfalls, that created a few extremely high values. The median values of 3,500 total coliforms, 1,000 fecal coliforms and 200 fecal streptococcus per 100 ml of water serve as our best estimates of bacterial contamination in the Black Creek watershed as a whole during low stream discharge. However, these figures do not accurately describe the fecal pollution that existed at many locales in the Black Creek watershed as some stations were far more polluted and others had coliform concentrations which approached the most stringent clean water guidelines.

TABLE 37
Stream Discharge Class By Date for Two Sampling Sites

Date	Average Daily Discharge m^3/sec Site 2	 Site 6	Discharge class
3-19-76	.048	.025	low
6- 7-76	.008	.004	low
8-23-76	.004	.000	low
11-29-76	.000	.002	low
3-28-77	1.007	.775	high
5-31-77	.001	.001	low

TABLE 38
Total Coliform, Fecal Coliform and Streptococcus Count - Low Discharge

	Total coliform	Fecal coliform	Fecal streptococcus
	Count/100 ml water		
Range	100-2,600,000	0-2,600,000	0-890,000
Median	3,500	1,000	200
Mean	164,668	109,114	19,114

4.4.2 Contamination at Low Flow

Because reliable estimates of bacterial contamination at specific sampling stations could not be made, the stations were grouped into six categories based on levels of discharge and organic pollution. When not carrying storm runoff, some streams in the Black Creek watershed maintained a base discharge from groundwater. Others ceased to have any discharge and in the summer months became a series of isolated pools. A few sections of stream had an intermittent flow arising from domestic waste effluent. Figure 15 outlines the location of these three flow regimes in the Black Creek watershed. The major source of sewage was the town of Harlan, but individual septic tank outfalls occurred throughout the watershed.

The grouping of stations was done by assessing the locality in relation to both the proximity of sewage outfalls and the stream discharge regime. Table 39 shows these groupings along with mean bacterial counts plus/minus the standard deviation for each group. The large standard deviations reflect the highly variable nature of the data caused in part by the wide range of environmental conditions encountered during low stream discharge. There were no significant differences between the group means due to the high variances. However, the mean bacterial counts did show trends consistent with a subjective assessment of organic pollution in each of the groups.

In Figure 16, the data for each group is presented to show the frequency of six levels of bacterial contamination. Groups B and F, stations with high levels of organic pollution, had broad distributions of total

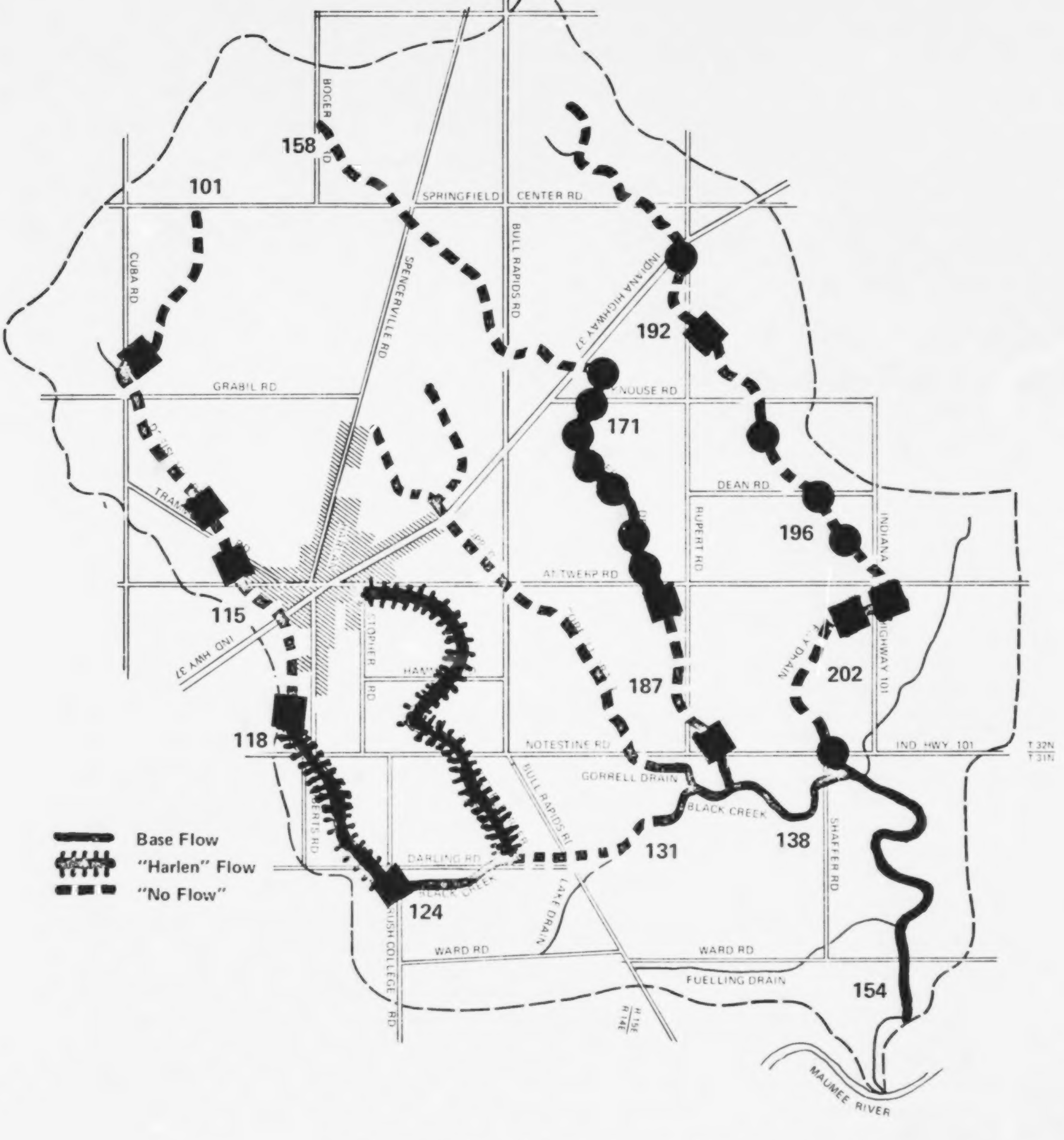
158
BOGER RD
101
SPRINGFIELD CENTER RD
CUBA RD
SPENCERVILLE RD
BULL RAPIDS RD
INDIANA HIGHWAY 37
192
GRABIL RD
NOUSE RD
171
DEAN RD
RUPERT RD
196
INDIANA HIGHWAY 101
ANTWERP RD
115
IND HWY 37
187
202
118
NOTESTINE RD
IND. HWY. 101
T 32N
T 31N
GORRELL DRAIN
BLACK CREEK
138
131
SHAFFER RD
DARLING RD
BLACK CREEK
124
LAKE DRAIN
WARD RD
WARD RD
FUELLING DRAIN
154
R 15E
R 14E
MAUMEE RIVER
Base Flow
"Harlen" Flow
"No Flow"

Figure 15. Flow Regimes in Watershed

TABLE 39
Surface Water Stations According to Stream Discharge and Organic Pollution

Group	Number of stations in group	Discharge Regime	Organic Pollution	Mean +- stand deviation (Count per 100 ml water) Total coliform	Fecal coliform	Fecal streptococcus
A	2	Isolated pool	Moderate	5,333 +-2,754	3,666 +-4,038	200 +-346
B	2	Intermittent flow	High	554,900 +-473,800	671,450 +-954,069	116,190 +-278,800
C	4	Intermittent flow	Moderate	16,010 +-5,903	3,850 +-7,424	480 +-539
D	4	Base flow	Low	7,243 +-14,398	4,079 +-13,508	300 +-568
E	6	Isolated pool	Low	2,316 +-2,640	895 +-1,030	216 +-432
F	2	Isolated pool	High	537,600 +-930,260	29,656 +-47,500	7,422 +-19,000

coliform counts and median values of 435,000 and 59,000 respectively. The moderately polluted groups, A and C, also had wide distributions but median total coliform counts were 4,000 and 3,450 respectively. The remaining two groups, D and E, had low levels of pollution, a narrower distribution of total coliform counts and median values of 2,850 and 1,750 respectively. The distribution of fecal coliform counts was very similar to that just described for total coliforms. The median values were as follow: highly polluted groups, 165,000 (B) and 7,200 (F); moderately polluted groups, 1,800 (A) and 950 (C); slightly polluted groups, 500 (D) and 400 (E). Fecal streptococcus contamination was slight except in the highly polluted areas where median counts were 5050 (Group B) and 1,600 (Group F). The remaining groups of stations had median counts less than 200 fecal streptococci per 100 ml water.

It is evident that, at low stream discharge, the degree of fecal contamination was dependent upon the proximity to sewage outfalls and the type of flow in the stream. The fecal coliform counts indicate that sections of the Black Creek drainage receiving septic waste have fecal contamination far in excess of any public health standards. Other areas of the drainage removed from nearby septic tank pollution were found to occasionally meet federal public health standards for fecal coliform contamination but generally these areas had twice the allowable limit of 200 fecal coliforms per 100 ml of water.

On 28 March, 1977, there was considerable surface runoff from agricultural land, and stream discharge in Black Creek was high (.775 cubic meters/sec). Table 40 summarizes the data collected during this runoff event. The mean and median values were not greatly different because septic tank effluent in the badly polluted stream sections was being diluted. The median values for total coliform, fecal coliform and fecal streptococcus counts were 5, 3, and 17 times greater, respectively, than the median values during low stream discharge (see Table 38).

The increase in total and fecal coliform counts was caused by higher counts at stations on Black Creek downstream of Harlan. The tributary drains not influenced by Harlan showed only a slight increase in coliform

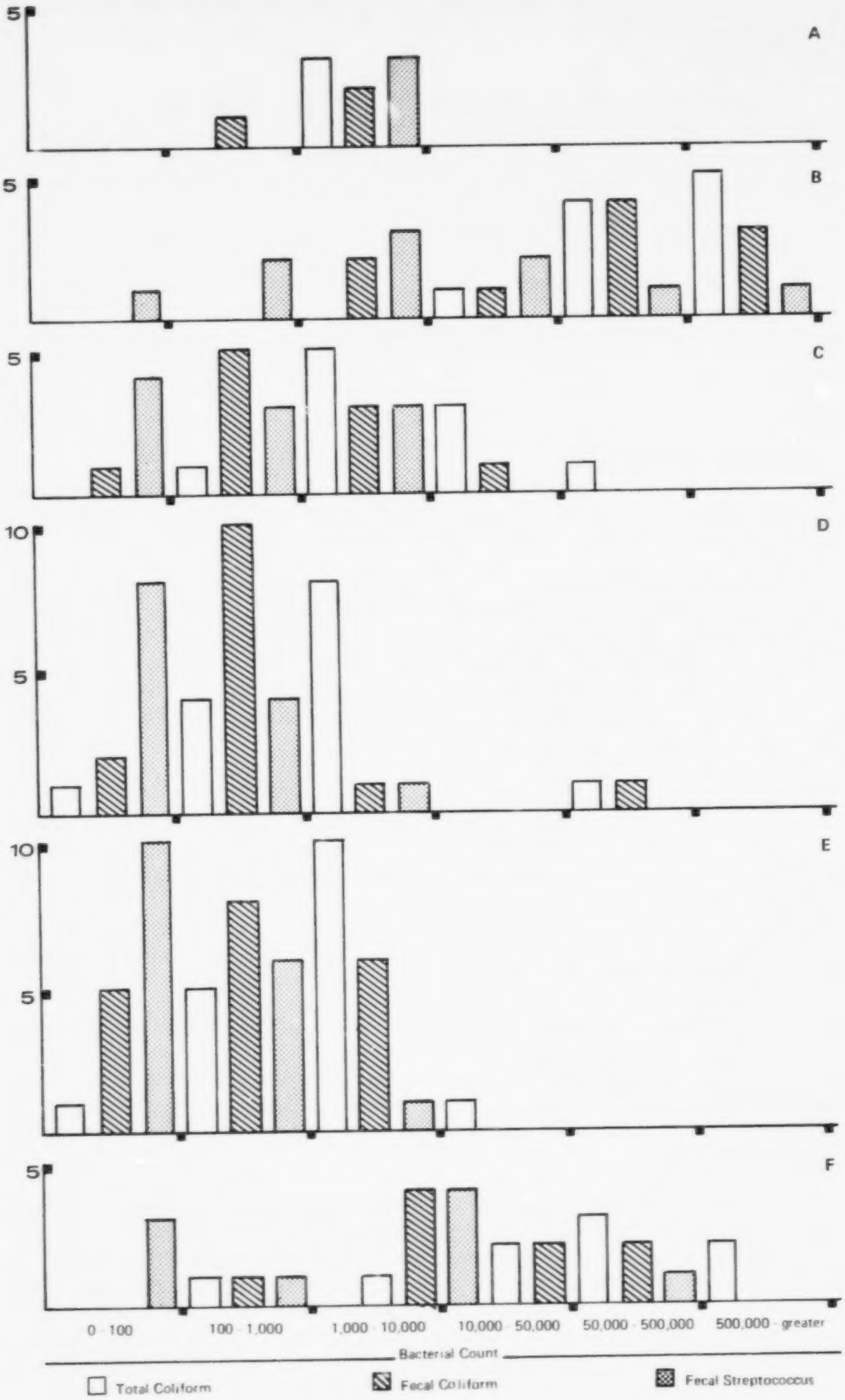

Figure 16. Frequencies of Levels of Contamination

TABLE 40
Coliform Counts at High Stream Discharge

	Total coliform	Fecal Coliform	Fecal Streptococcus
	--------count/100 ml	water---------	
Range	600-92,000	0-36,000	0-10,000
Median	18,000	3,350	3,500
Mean	25,960	4,865	4,220

contamination over low stream discharge levels (see Table 41).

TABLE 41
Coliform Counts at High Stream Discharge

	Total coliform		Fecal coliform	
	------------count per	100 ml	water-----------	
	low discharge	high discharge	low discharge	high discharge
Stations downstream of Harlan	2,850	32,000	600	5,300
Stations not influenced by Harlan	1,800	2,500	500	700

These observations led us to two conclusions:

1) Storm runoff from agricultural land in the Black Creek watershed was not substantially different from low stream discharge runoff in the levels of total and fecal coliform contamination, and,

2) Highly organic, contaminated material deposited at septic tank outfalls was scoured and flushed downstream during the storm event.

The increase in fecal streptococcus contamination during high flow was observed at all stations on the Dreisbach Drain. A grassed waterway and an open ditch in this section of the watershed carried between 5 and 10 thousand fecal streptococci per 100 ml of water. A slightly lower level of contamination (3,000-9,000) was maintained along the lower Dreisbach drain, the Richelderfer Drain and Black Creek. The remaining tributary drains had from 0 to 3,500 fecal streptococci per 100 ml of water. Thus the Upper Dreisbach Drain agricultural area and the town of Harlan were the major identifiable areas of fecal streptococcus contamination at high stream discharge. The dominant type of livestock handling in the Dreisbach subwatershed is open grazing in pastures and confinement in small barnlots. In these areas the contamination was over an order of magnitude greater than the levels of pollution observed at low stream discharge. The other monitoring stations in the Black Creek watershed showed the storm runoff to be only slightly more contaminated than low stream discharge runoff. It is concluded that some livestock operations were responsible for substantial fecal pollution of storm runoff in the Black Creek watershed.

4.4.3 Bacterial Counts,Maumee,Wann Ditch

Surface water samples were collected from the Maumee River and the Wann Ditch to facilitate a comparison of the coliform contamination in Black Creek with the coliform contamination in its receiving body of water (Maumee River) and a similar creek adjacent to the Black Creek watershed. The Wann Ditch lacks any concentrated urban area and is comparable to the tributary drains of Black Creek not influenced by the town of Harlan (sampling Group E). As expected, the counts were similar to those reported from stations in Group E. The trend for increasing fecal streptococcus counts at high stream discharge was also observed on the Wann Ditch.

Counts observed in the Maumee River were quite wide-ranging, probably being a function of discharge, as the highest counts were recorded in the spring. Fecal coliforms were generally fairly low (200-500 counts per 100 ml), but at high discharge, the counts increased an order of magnitude (400-15,000). Fecal streptococci were detected only once at the Maumee River station during a period of high stream discharge (March 28,1977). Compared to the waters of the Black Creek drainage, the Maumee River had approximately the same concentration of total coliforms but lower concentrations of fecal coliforms and fecal streptococcus (excluding periods of high stream flow).

4.4.4 Bacterial Counts in Tile Drainage Water

Twenty tile drainage systems were chosen for sampling on the basis of the soil types being drained. The data record is too incomplete to determine if soil type was a factor affecting the level of fecal pollution from tile systems. Of 120 attempted sample collections, 55 could not be made because the tile systems were not flowing. In addition, six of the tile lines were found to be connected to septic tank systems. As a result, conclusions about fecal pollution from tile systems are rather limited and have been based on the following observations.

The tile drainage stations are broken down into the septically polluted tiles and the non-septically polluted tiles in Table 42. A further division is made between the low flow and high flow sampling dates. Predictably, the septically-polluted tiles had very high average values during low flow when there was very little dilution of septic waste by natural drainage water. At high flows these same tiles carried far lower concentrations of all three bacteria because of the dilution by sub-surface drainage water. The non-septically polluted tile systems had fairly low levels of coliform contamination that remained unaffected by discharge rates. The total coliform counts were very similar at high and low discharge and a small increase in fecal coliform concentrations at high flow resulted from two tile stations with surface water inlets having higher values.

The increase in fecal streptococcus contamination of non-septically polluted tile systems at high flow was a general occurrence recorded for the majority of the tiles sampled. At low flow, only 1 of 14 stations had a fecal streptococcus count above 100, while at high flow 12 of 14 stations had counts over 100. However, the magnitude of increase was not generally as great as the average figures in Table 42 indicate. At high flow, 10 of the 14 stations had fecal streptococcus counts between 100 and 500, while two tiles with surface water inlets had counts an order of magnitude

TABLE 42
Coliform Counts for 6 Septically Polluted and 14 Non-septically Polluted Outlets

		Low Flow mean	n		High Flow mean	n
Septically Polluted	TC	329,500	21	TC	9,740	5
	FC	60,683	21	FC	2,340	5
	FS	29,662	21	FS	5,880	5
Non-septically Polluted	TC	2,327	24	TC	2,286	14
	FC	60	25	FC	430	14
	FS	12	25	FS	2,150	14

greater. Non-septically polluted tile drainage systems were an identifiable source of fecal pollution at high stream discharge, although the degree of contamination was not great.

4.4.5 Fecal Coliform/Fecal Strep Ratios

An indication of the source of fecal pollution is given by the fecal coliform/fecal streptococcus ratio (FC/FS). A ratio greater than 4 indicates human sources of pollution, a ratio less than 1 indicates an animal source and a ratio between 1 and 4 indicates combined human and animal fecal pollution. In the Black Creek watershed, at low flow, the dominant source of fecal contamination was the human septic waste effluent, but there was a significant ($p<.01$) shift from human to mixed human and animal sources of pollution when discharge increased (see Table 43). This observation further supports the conclusion that livestock operations had a substantial impact on the fecal contamination of storm water runoff. Stations in the upper Dreisbach agricultural area exhibited the greatest degree of fecal contamination from livestock, while stations in other areas showed either livestock sources or mixed human and animal sources.

TABLE 43
The Number of FC/FS Observed and Expected FC/FS Determinants

		Low flow	High flow
Human sources	FC/FS > 4	45(36.7)	3(11.3)
Mixed sources	FC/FS 1-4	14(15.3)	6(4.7)
Livestock sources	FC/FS < 1	6(13)	11(4)

$x2=24.44$, $p<.01$

4.4.6 Biochemical Oxygen Demand

4.4.6.1 BOD

Samples were collected for biochemical oxygen demand (BOD) analyses during a major storm event on June 30, 1977 (7.1 cm rainfall). Grab samples were collected in a 2 liter polyethylene containers and refrigerated until laboratory set-up was initiated the next day. The grab sample locations are noted in Table 44. In addition, composite samples were made from the water collected by automated pump samplers at sites 2 and 6. At stream stages above one foot, the automated pump samplers collected a water sample every 30 minutes during the course of the storm event. Composite samples for BOD analysis were made at the end of the event by combining 50 ml of water from each sample taken by the pump sampler. Laboratory analysis for BOD was done by Pollution Control System, Inc. (Laotto, Indiana) following the procedures of Standard Methods (American Public Health Association, 1971).

TABLE 44
BOD During Ascending Flow of Storm Event

Station	BOD (mg/l)	Predominant Feature of Watershed
Grab samples		
296	12.0	Small watershed, Amish farming
297	6.6	Small watershed. conventional farming
127	14.0	Dreisbach Drain, urban buildup
128	16.0	Richelderfer Drain, urban buildup
165	16.0	Wertz Drain, Amish farming
310	480.0	Tile Drain, confined feeding operation
Composite samples		
2	6.3	Smith-Fry Drain, conventional farming no urban buildup
6	9.3	Dreisbach Drain, Amish farming, urban buildup

4.4.6.2 RESULTS

All grab samples were taken during the ascending climb of the storm hydrograph. Results are listed in Table 44. Two samples were collected from adjacent small watersheds (60 acres) in the rolling uplands. The watershed with Amish farming practices had twice the BOD concentration in runoff water as the area under a conventional farming operation. It appears the unconfined livestock in the Amish area substantially increased the amount of organic matter in surface runoff.

Grab sample 310 was taken from a large tile outlet known to have surface inlets in the vicinity of a large confined livestock feeding operation. Although this operation is equipped with properly designed animal waste holding facilities, surface runoff from the barnyard area does reach the tile drain and eventually Black Creek. The BOD at station 310 was exceedingly high, 480 mg/l, equivalent in strength to raw sewage (Hynes, 1960). The tile outlet was sampled during the initial phase of the storm and surface runoff was just beginning so the volume of discharge was small. It is doubtful that BOD concentrations remained this high during peak storm runoff because dilution would be greater. In terms of total BOD loading, such a confined feeding operation cannot be considered a major source within the watershed, but it is the type of source that raises BOD concentrations in stream above the concentrations found in runoff from cropland. Also, highly concentrated organic matter delivered to stream in this manner could be damaging to the localized section of stream at the tile outlet if rainfall and runoff are not sufficient to dilute and flush away the organic matter.

The composite samples collected from the Smith-Fry drain (site 2) and the Dreisbach drain (site 6) also illustrate the effect of urban build-up and Amish farming practices on BOD concentrations. The Smith-Fry watershed lacks any urban influence and is farmed predominantly by conventional methods while the Dreisbach watershed contains the town of Harlan and a large number of Amish farmers. Composite BOD concentrations for site 2 and 6 were 6.3 and 9.3 mg/l respectively. Precise BOD loading data has not been calculated yet, but to arrive at a first approximation, composite concentrations were multiplied by the average daily discharge computed for June 30, 1977. Estimated loadings of BOD for the storm event were 320 kg and 220 kg at sites 2 and 6 respectively. More rainfall and runoff in the Smith-Fry watershed accounted for the greater loadings at site 2. Averaging data for both watersheds the rate of BOD export from the Black Creek watershed for this storm was approximately one-third kilogram per hectare.

Grab samples were taken on three major drains of Black Creek prior to peak flows on June 30. BOD concentrations were similar in all three samples ranging from 14 to 16 mg/l. Two of the samples were taken downstream from the town of Harlan and the other from a predominantly Amish farming area. The urban area with its septic effluent and the Amish area with a large number of unconfined livestock appear to be the factors that created high BOD concentrations in stream flows (14-16 mg/l) compared to runoff from conventional cropland (6.6 mg/l).

4.4.7 Fish Kill Caused by Organic Pollution

On 28 September 1977 several thousand gallons of manure slurry were accidentally discharged into Black Creek when an animal waste holding lagoon was emptied directly onto adjoining cropland. The slurry entered a subsurface tile network through broken tile lines and/or surface inlets and was delivered to the stream with very little dilution (Table 45). The impact at the outfall was devastating and low stream flows were inadequate to dilute the pollutant to non-toxic levels. The material moved downstream as a slug which could be visually detected. Three downstream samples had very high BOD (130-300 mg/l) even prior to the arrival of the main slug of pollutant. Ammonia N concentrations were also greatly elevated (Table 45).

Fish mortality was severe in the entire 9 kilometers of stream below the spill. Mortality probably resulted from low oxygen levels and/or an ammonia toxicity. Accidental or intentional discharge of organic pollutants from animal waste holding facilities can create gross organic pollution in streams when discharge is low and potential damage is the greatest. Wide spread organic pollution from other sources (septic tanks and unconfined livestock) is greatest at high stream discharge when dilution reduces the impact on aquatic life.

TABLE 45
BOD and Ammonium N Concentrations During Fish Kill

Sample Location	BOD mg/l	Ammonia N mg/l
Upstream	2.1	1.2
Source (tile line)	28,000	2,400
Downstream 100 m	7,200	600
Downstream 580 m	130	11
Downstream 1720 m	220	18
Downstream 2440 m	300	20

4.4.8 Pesticides and Heavy Metals

Several spot checks were made for the presence of pesticide residue and for heavy metals in sediment, in fish and in water samples according to the procedures outlined in Section 0.0.2. Results of this analysis are presented in Table 46 and are summarized in Table 47. Sampling was done under low-flow conditions and may not reflect the situation during storm events. Overall, a low level of contamination was found.

TABLE 46
Pesticide and Heavy Metal Concentrations

Location	Dieldrin	DDE	PCB's	2-4-5-T	Cd	Hg	Zn
Sediment Samples							
401	ND	ND	ND	-	0.77	ND	2.69
402	ND	ND	ND	-	0.66	ND	2.24
403	ND	ND	ND	-	0.64	ND	2.28
404	ND	ND	ND	-	0.94	ND	1.85
405	ND	ND	ND	-	1.08	ND	1.55
406	ND	ND	ND	ND	1.51	ND	1.66
407	ND	ND	ND	-	2.18	ND	2.90
408	ND	ND	ND	-	ND	ND	2.46
409	ND	ND	ND	-	.34	ND	ND
410	ND	ND	ND	-	.34	ND	1.55
411	ND	ND	ND	-	.37	ND	1.40
412	ND	ND	ND	ND	1.15	.003	1.56
413	ND	ND	ND	-	1.97	ND	4.46
414	ND	ND	ND	ND	2.65	.005	4.47
Fish Samples							
415	0.012	0.012	0.117	-	ND	0.092	14.4
416	0.013	0.017	0.070	-	ND	0.042	20.2
417	0.027	0.021	0.265	-	ND	0.008	21.8
418	0.031	0.027	0.140	-	0.18	0.009	19.1
419	0.031	0.031	0.182	-	0.16	0.036	19.2
420	0.047	0.021	0.142	ND	ND	0.021	12.2
421	0.022	0.014	ND	-	ND	0.051	16.6
422	0.013	0.007	ND	-	ND	0.077	18.2

Table 46 (continued)

423	0.086	0.014	0.086	-	ND	ND	13.3
424	0.010	0.015	0.108	-	ND	0.023	24.2
425	0.011	0.010	0.111	-	ND	0.041	17.5
426	0.004	0.009	ND	ND	ND	0.050	23.4
427	0.009	0.023	ND	-	0.15	0.047	23.9
428	0.014	0.008	ND	-	ND	0.030	16.4
429	0.021	0.012	0.173	-	ND	0.076	15.7
430	0.015	0.012	0.211	-	ND	0.102	22.6
431	0.017	0.018	0.121	-	ND	0.174	17.3
432	0.009	0.010	0.113	ND	ND	0.078	22.3
Water Samples							
433	ND	ND	0.0004	-	0.113	0.0002	0.029
434	ND	ND	ND	-	0.099	0.0002	0.022
435	ND	ND	0.0002	0.003	0.052	0.0002	0.021
436	-	-	-	-	-	-	-
437	ND	ND	ND	ND	0.037	0.0002	0.020
438	ND	ND	ND	-	0.029	ND	0.017
439	ND	ND	ND	-	0.026	ND	0.010
440	ND	ND	ND	0.001	0.038	ND	0.014

Note: Concentrations expressed in ppm
fish /g wet weight
water /g ml
ND = not detected
- = not determined

TABLE 47
Summary of Pesticide and Heavy Metals Detected and Not Detected

Medium	Substances Not Detected	Substances Detected	Number Samples	Number Occurences	Max.	Min.	Mean
					---Concentrations---		
Water	Atrazine	2, 4, 5,-T	2	2	0.003	0.001	0.002
	Alachlor	PCB's	7	2	0.0004	0.0002	0.0003
	Carbofuran	Cadmium	7	7	0.113	0.026	0.056
	Malathion	Mercury	7	4	0.0002	0.0002	0.0002
	Dieldrin	Zinc	7	7	0.029	0.010	0.019
	DDE						
Sediment	Atrazine	Cadmium	14	12	2.65	0.34	1.19
	Alachlor	Mercury	14	2	0.005	0.003	0.004
	Carbofuran	Zinc	14	13	4.47	1.55	2.39
	Malathion						
	Dieldrin						
	DDE						
	PCB's						
	2, 4, 5,-T						
Fish	Atrazine	Dieldrin	18	18	0.086	0.004	0.022
	Alachlor	DDE	18	18	0.031	0.007	0.016
	Carbofuran	PCB's	18	13	0.265	0.070	0.140
	Malathion	Cadmium	18	3	0.18	0.15	0.16
	2, 4, 5,-T	Mercury	18	17	0.174	0.008	0.053
		Zinc	18	18	24.2	12.2	18.8

Trace levels of 2, 4, 5,-T in water was found to persist after ditch bank maintenance with herbicide sprays. Higher concentrations may exist immediately after the maintenance procedure.

Low levels of organochlorines were detected in fish, but not in sediment. This suggests that there is currently no significant loading of these insecticides. Fish maintain a small amount of pesticide residue, but this is well below acceptable levels for human consumption as determined by the Food and Drug Administration. Effects on the fish life cycle are considered minimal. The level of PCB's detected in fish tissue were low, and are not an immediate cause for concern to humans or to fish life. However, PCB's were also found in water which presents evidence of continued loading to the aquatic system.

Heavy metals were found in low concentrations and are considered to be not much different than background levels. The concentrations are not a concern to human health.

4.5 FISH STUDIES

4.5.1 Fish Sampling

Sample stations (see Section . 3.3.1 were chosen to include riffles and pools and were paced off to 100 m lengths. In the Wertz Woods a set of three pools with combined length of approximately 30 m was sampled. Minnow seines (1.2 x 4.5 m) with 6 mm mesh were used in most sampling. A seine was placed at the lower end of a sample area and at least two seine sweeps were made downstream through the area. For more complex areas such as Wertz Woods stations were broken into smaller segments and seined until capture rates declined to near zero. Typically this required three to six seine hauls in the most complex streams sampled.

Fish samples were preserved in 20% formalin solution until a synoptic collection was developed. Thereafter, most were released immediately after field tabulation. Identification of fishes followed classification of Trautman (1957) and Nelson and Gerking (1968).

4.5.2 Habitat Structure

Stream habitat structure was measured in June and September 1975, and March 1976 for three dimensions: depth, bottom type, and current. Four depths, nine bottom substrates, and five current categories were recognized (Table 48). Stream depth categories were chosen as representative of habitats found in the small streams sampled: 0-5 cm corresponded to shallow edges and riffles, 5-20 cm to riffles and shallow pools, 20-50 cm to pools, and greater than 50 cm to deep pools. Bottom types were categorized into physical and biotic structures. Among the physical forms, categories 1-5 corresponded to alluvial material of increasing size from silt to rocks with category 6 as clay parent material (clay pan). Biotic categories (7 and 8) included vegetation (aquatic plants and filamentous algae) and litter (leaves, twigs and branches). A miscellaneous category, 9, was reserved for unusual items such as bedrock slabs or large tree trunks. Currents were correlated with specific water velocities and were gauged by observing the movement of water about a measuring pole.

Point samples were taken in a regular fashingin each study area. Beginning 10-20 cm from the left bank, points were taken at 1 m intervals across the stream. For very narrow stream (maximum 1 m wide) such as Limbo Creek and Wertz Woods at low flow, 0.33 m intervals were used. Repeated

TABLE 48
Categories for Habitat Analysis

Dimension		Category Number and Description								
		1	2	3	4	5	6	7	8	9
Depth	Range (cm)	0-5	5-20	20-50	>50					
	Description	very shallow	shallow	moderate	deep					
Current	Flow Velocity (m/sec)	<.05	.05-.2	.2-.4	.4-1.0	>1.0				
	Description	very slow	slow	moderate	fast	torrent				
Bottoms	Diameter (mm)	<.05	.05-2	2-10	10-30	>30	other			
	Description	silt	sand	gravel	pebble	rock	clay-pan	vegetation	litter	misc.

sets of points were taken across the stream at 5 m intervals moving upstream. Sample data showed that a minimum of 90 to 160 points were required at structurally complex sites (Wertz Woods and Indian Creek) and 60 to 80 points for simple areas (Black Creek) for adequate measurement of habitat diversity. Habitat sampling was generally conducted on the same day as fish sampling with the exception of September 1975 when Black Creek habitat samples were taken one week after fish sampling. No changes in weather conditions occurred during this interval.

Habitat diversity was calculated using the Shannon-Weiner equation. Diversities were calculated for each habitat dimension alone and then in combinations of depths and bottoms (36 categories), currents and bottoms (40 categories), and finally depths, bottoms, and currents (180 categories). Only certain combinations of these dimensions existed in these streams. For instance, we found no rock-bottom torrents greater than 50 cm deep, or silt-bottom riffles.

Combinations of habitat dimensions were tried to determine which dimension or combinations were better predictors of fish species diversity. The effect of combining dimensions increased the number of categories geometrically and thereby increased the habitat diversity index additively since this index is an exponent.

Mean habitat indexes were calculated for each dimension by averaging the number of values for each category. This allowed each stream site to be characterized as shallow, sandy, slow, etc. In the bottom-type dimension only the alluvial categories (1-5) represent continuous variation, so calculation of mean habitat indexes was restricted to those categories.

4.5.3 Species Composition and Distributions

A total of 35 species of fish representing 24 genera and 11 families have been collected in the Black Creek watershed basin (Table 49). This represents about 21 percent of the species and 41 percent of the families known from the State of Indiana (Nelson and Gerking 1968). A recent IJC report (1975) on the fishes of the Maumee River lists 91 species from the Maumee Basin in a survey by the Ohio Department of Conservation and Trautman (1957). Therefore about 35 percent of the fishes known from the basin have been collected in Black Creek. It is significant that most species found in Black Creek show either stable population trends (32 species) or are decreasing in the Maumee Basin (3 species). The three declining species are Northern Pike, Redear Sunfish, and Creek Chubsucker. The sunfish in Black Creek escaped from a farm pond and the Pike were captured only in the spring of 1974. The Chubsucker was common in Wertz Woods but it has disappeared following siltation after bank stabilization in upstream areas. About a dozen species collected in Black Creek seem to be declining in abundance although they are not experiencing declining populations in the Maumee Basin according to the IJC report. Other species known from Black Creek are the most tolerant forms to be expected in first, second, and third order streams in an agricultural watershed. The minnow family (Cyprinidae) is represented by the largest number of species (12) with the sunfish family (Centrarchidae) being represented by the second largest number of species (8). The minnows make up the largest number of individuals in the basin but in terms of biomass the sucker family (Catastomidae) is the dominant group, especially during the late spring and early summer migration period.

TABLE 49
Fish Species Collected in Black Creek

Scientific (Common) Name	Status in the Black Creek Basin	Distribution			
		20	18	20	Wertz Wd
Aplodinotus grunniens (Freshwater Drum)	Very rare fall migrant (One specimen)				
Umbra limi (Central Mudminnow	One specimen				
Semotilus atromaculatus (Creek Chub)	Distributed throughout the area; some movements, especially influx in spring.	C	V	V	V
Pimephales promelas (Fathead Minnow)	Most abundant in upstream areas.	V	V	V	V
P. notatus (Bluntnose Minnow)	Common throughout the basin but most abundant in small streams below P. promelas areas.	C	V	V	V
Ericymba buccata (Silverjaw Minnow)	Common throughout the basin especially in silty to sandy area.	V	V	V	V
Campostoma anomalum (Stoneroller)	Uncommon but distributed throughout.		U	U	C
Notropis cornutus (Common Shiner)	Abundant to common throughout; some migration in spring.	R	U	C	V
N. stramineus (Sand Shiner)	Generally restricted to areas in the main channel of Black Creek; move upstream to some extent in late spring and early summer; often found in same areas as E. buccata.		C	V	
N. spilopterus (Spotfin Shiner)	Common below station 12; uncommon in rest of basin except in fall when large numbers invade.	C	C	V	R
N. umbratilis (Redfin Shiner)	Rare throughout the basin, except in early summer.	C	U	C	R
Phenacobius mirabilis (Suckermouth Minnow)	Rare in Black Creek below station 15.		R	R	
Notemigonus chrysoleucos (Golden Shiner)	Uncommon below station 12; resident population in Wertz Woods.			R	C
Cyprinus carpio (Carp)	Common and often large in main Black Creek channel.		R	U	

Erimyzon oblongus (Creek Chubsucker)	Uncommon in basin except common in Wertz Woods.				C
Catastomus commersoni (White Sucker)	Abundant in spring migration (esp. large individuals); permanent residents throughout Wertz Woods.	R	R	U	V
Carpiodes cyprinus (Quillback Carpsucker)	Common in Black Creek near Maumee River; sporadic in rest of area, most abundant in late summer and fall.			U	
Moxostoma sp. (Redhorse)	One specimen				
Fundulus notatus (Black-striped Topminnow)	Common to abundant, esp. in areas with dense growth of aquatic plants and in late summer and early fall.		C	C	R
Percina maculata (Black-sided Darter)	One specimen.			R	
Etheostoma nigrum (Johnny Darter)	Common, esp. in rocky areas.		R	U	
E. spectabile (Orangethroat Darter)	Uncommon		U	R	
Lepomis cyannellus (Bluegill)	Common throughout	R	R	C	U
L. macrochirus (Green Sunfish)	Common throughout	V	U	V	V
L. microlophus (Redear Sunfish)	Collected occasionally	C	U	C	R
L. humilis (Orange-spotted Sunfish)	Rare				
L. gibbosus (Pumpkinseed)	Rare	R			
Pomoxis nigromaculatus (Black Crappie	Rare			R	
P. annularis (White Crappie)	Rare summer immatures			R	
Micropterus salmoides (Largemouth Bass)	Young sporadic in several areas Also widely distributed in 1977.	R	R	R	R
Labidesthes sicculus (Brook Silverside)	One individual caught in Black Creek near Maumee River.				
Ictalurus natalis (Yellow Bullhead)	Small individuals sporadic throughout basin; some large residents in Wertz Woods		U	U	R

I. melas (Black Bullhead)	and below station 12.	R		
Esox lucius (Northern Pike)	Several large individuals seen or captured in spring 1974.			
Dorosoma cepidianum	Common near Maumee River; many migrate upstream in late summer and fall.		R	U

Distribution at first (Station 20), second (18), and third (12) order stations of the watershed plus Wertz Woods using the following abundance classes:

V -- Very Common -- > 85% of samples
C -- Common -- 50 to 80% of samples
U -- Uncommon -- 20 to 50% of sampels
R -- Rare -- < 20% of samples

Predictably, the similar physiognomies and geographic proximity of Black Creek and Wann Creek resulted in nearly identical fish faunas. However, the fauna at the sample station on Wann Creek was exceptionally rich; 17 species were common (caught more than 50 percent of the samples) while at Black Creek's station 18 (of similar size and stream order), only 7 species were common. Overall, one station in the Wann Creek drainage had more common species than any area on Black Creek and more species were captured per sampling period. The first order stream in the Wertz Woods was also surprisingly rich in comparison the rest of Black Creek; 11 species were common in Wertz Woods while at station 20 in Black Creek only 8 species were common. Only station 12 had more common species (12). Overall, the number of species captured per sample in Wertz Woods was similar to station 12 but more consistent. The Wertz Woods yielded the highest fish species diversity for the Black Creek drainage. Typically each station on Black Creek [illegible] dominated by a few species, resulting in low fish species diversity, [illegible] Wertz Woods and Wann Creek had consistently more species and more equitable abundance distributions even though Wertz Woods was first order and Station 12 was a third-order stream.

4.5.4 Seasonal Changes in Fish Communities

The average number of fishes per station peaks in the Black Creek watershed in early spring but the magnitude of peaks varies from year to year depending on the activities of man and rainfall amounts (Karr and Gorman 1975). Spring peaks (March-April) are associated with spawning migrations of fishes from downstream areas, including the Maumee River. Summer declines in Black Creek are associated with disappearance of larger fishes due to low water levels. An increased capture rate in late summer and fall results from increased catchability of young of the year and some fall migrations. Late winter sampling show that densities decline as a result of some downstream migration and natural mortality during the winter. Larger fishes were relatively uncommon in upstream areas except during the spring migration period of March and April. Communities in headwaters were dominated by small minnow species such as Pimephales spp., Ericymba buccata, and juveniles of Semotilus atromaculatus. Fishes at downstream stations tended to be larger and less numerous. Overall, upstream areas had higher densities of smaller fishes such that headwater and downstream areas support similar biomasses per meter of stream.

4.5.5 Habitat,Fish Community Diversity

There is a significant relationship between habitat diversity and fish species diversity when Black Creek data are combined with data from two other stream systems (Gorman and Karr 1978). Significantly the relative importance of the three dimensions -- bottom, current, and depth -- varies among stream systems. Neither bottom nor depth diversities are good predictors of fish species diversity of Black Creek because of the uniform nature of the habitat components due to ditching activities. Algal blooms characteristic of dry periods with low flow conditions are also correlated with exceptional low fish diversities. These blooms are associated with stream reaches lacking shading vegetation. Further, water temperatures tend to be very high in such areas: 28 degrees C as compared to 19 degrees C in the same stream where it is shaded in a woodlot (Karr and Gorman 1975).

4.5.6 Effects of Channel Modification

The effects of channel and bank modifications can most easily be demonstrated by examining changes in the fish communities at station 15 on Black Creek.

The first 50-m sample from station 15 was made on 12 April 1974 when 210 fish were captured. Fifty-nine of these fish had average total lengths of over 150 mm indicating the high biomass in that section of stream. Larger individuals were creek chubs, white suckers, common shiner, and green sunfish. Mean weight per individual was 25.85 gms and biomass density was 108.6 g per meter of stream. After bottom dipping and bank modifications in late spring 1974 fish densities declined and have remained low. Table 50 summarizes the fish community data for April.

TABLE 50
Fish Community Density During April

	Number of fish per meter	Mean Weight (g) per individual	Biomass (g) per meter
April 1974	4.2	25.85	108.6
April 1975	.34	2.10	1.0
April 1976	.05	<0.5	-

Fish densities in 1977 were also quite low at station 15 although they were high in nearby upstream areas with little or no channel modification.

At the time of the April 1974 samples the stream showed the effects of earlier channel modification but erosion and deposition areas with some segregation of particle sizes was evident. The mean depth of the stream was near 50 cm while following channel modification in 1974 water depth averaged only about 10 cm. The decline in fish populations at this station seems primarily attributable to channel modifications reducing depth and bottom diversity. Similar patterns of change in fish densities have occurred at other Black Creek sample areas.

These changes in streams modified by man's activities are in sharp contrast to the more damped oscillations of fish abundances in Wann Creek and in several pools associated with the Wertz Woods along the Wertz Drain. In Wertz Woods as a number of species characteristic of downstream areas persisted throughout the year. Fish marked with a cold-branding technique were commonly recaptured in Wertz Woods while fish marked in other areas in the Black Creek watershed were rarely recaptured. It is not clear from our data whether fish outside Wertz Woods disappeared due to high mortality or leaving the watershed; both factors are probably very important.

Even relatively protected sections of stream like that in Wertz Wood may be subjected to high mortality. The very dry period in late 1976 resulted in almost total mortality throughout upstream areas in Black Creek. Because of deep pools fish in Wertz Woods persisted later than fish in other areas. However, most were killed before the onset of winter and the few remaining individuals were killed by the severe cold weather of early 1977.

Upstream migrations in 1977 were similar to those in earlier years and resulted in recolonization of the whole watershed. However, fish have not been able to reestablish resident populations in Wertz Woods. As demonstrated in 1975 (Karr and Gorman 1975) the meandering pool and riffle topography of Wertz Drain in Wertz Wood resulted in deposition of about 28 percent of sediment carried by Wertz Drain. Although we do not have direct evidence, indirect evidence suggests that declining sediment loads are due to physical processes (Unit Stream Power of hydrology) rather than action of biotic systems (Karr and Schlosser 1977).

Construction on the Wertz Branch upstream from Wertz Woods was instrumental in halting the recolonization of Wertz Woods in 1977. The construction activity itself and subsequent erosion of unstable bank and channel in Wertz Branch yielded large amounts of sediment. Grab sampling of several runoff events revealed that sediment concentrations from the Wertz Branch were 4-8 times greater than from undisturbed channels. As this sediment moved downstream it was deposited in downstream areas (especially Wertz Woods). This deposition has reduced the diversity of depth, bottom and current characteristics in Wertz Woods and prevented reestablishment of resident fish populations. Monitoring is continuing to determine how long this problem will persist.

It should be clear from these results and the more detailed presentations of Karr and Schlosser (1977) and Gorman and Karr (1978) that attempts to improve water resources must involve broad based, multi-purpose program. Management plans which produce clean water in the absence of suitable habitat diversity will not improve the biota of waterways. Low quality stream biotas may result from low water quality, poor habitat diversity, seasonal low flows and other factors. All of these problems must be addressed before incremental improvement can be expected in a wide range of water resource characteristics.

4.5.7 Stream Disturbance and Fish Communities.

Stream environments are naturally unstable; *e.g.*, due to seasonal variation in rainfall, flow volumes do not remain constant in most streams. However, flow volumes are relatively predictable in most natural streams. Environmental extremes, such as high water and droughts, occur predictably from season to season and year to year. Fishes have evolved physiologies and behaviors to minimize mortality during these extremes, (*e.g.* migration to more suitable habitat, moving into pools during dry periods, etc.).

Structurally diverse natural streams typically have a great deal of buffering capacity: meanders tend to moderate the effects of floods, pools offer excellent refuges for fishes during dry spells, and tree shade decreases heat loads and minimizes the oxygen-robbing effects of decomposing and extensive algal blooms.

The reliability of stream environments is reduced by man's modifications of these systems to suit his needs. Ditching increases stream gradients by meander removal and channel shortening. Also, bottoms are dredged to create a uniform, pool-less, unstable substrate. These attempts to increase drainage efficiency result in little buffering from floods and droughts and increases their severity.

Other stream modification procedures which enhances instability is the removal of shade-producing vegetation, and the sloping of banks. This maximizes solar heating of the water and increases problems from algal blooms. Also, massive deforestation of drainage basins enhances the impact of floods and causes silt pollution problems via increased soil erosion (see review by Karr and Schlosser 1977). The discharge of sewage effluents may also be detrimental to fish, but in areas below the septic zone, the more constant flow of water may help to stabilize the downstream fish populations during drought periods (Karr and Dudley 1976).

Some indication of the effect of these factor can be obtained by comparing studies in Black Creek with work from other stream areas. Most stream reaches in Black Creek have been modified significantly in the past few years. The only significant exception is Wertz Woods. A sample station on Wann Creek was modified about a decade ago but has developed some pool and riffle characteristics along with a diverse vascular plant community in and near the stream channel. Finally, Indian Creek in Tippecanoe County west of Lafayette, Ind. has also been studied. Indian Creek is an agricultural watershed but most of the stream has not been ditched. Thus, natural stream topography has been maintained and most of the channel is shaded by trees. The degree of buffering present among our study streams was evident in the structure and stability of the resident fish communities (Table 51). Community structure in Black Creek was simple in each area and unstable. Wann Creek usually had a more diverse community but seasonal stability was low. Indian Creek and Wertz Woods, however, had both diverse and relatively stable communities.

Even though Wann Creek was subject to the same unstabilizing influences as Black Creek it showed remarkable recovery. The stream's habitat structure was more diverse, with greater pool formation and dense bulrush thickets which stabilized the stream channel and provided partial shading. This stream structure supported a more diverse community but not a more stable one. The unstabilizing influences of massive stream and watershed

TABLE 51
Percent Change - Number Species 4 Areas

Stream	Number of Fish Species	Number of Stations	Mean Percent Change June-Sept. 1975
Black Creek	5(1)*	5(1,2,3)*	68
Wann Creek	14(2)	1(2)	70
Wertz Woods	9(1)	1(1)	40
Indian Creek	10(1)	2(1,2)	33

* Numbers in parenthesis indicate stream order(s).

modification tend to strip the stream ecosystem of some equilibrium capability (homeostatic mechanism). Thus, Black Creek and Wann Creek biotic communities and habitats changed dramatically seasonally.

In contrast, Indian Creek and Wertz Woods had remarkable complexity and stabilized habitat structure allowed the stream some degree of homeostatic equilibrium and was reflected in the stability of the fish community.

From this study of an assortment of streams it is evident that natural processes and structures enhance the reliability of a basically unstable system. Habitat complexity increases community diversity and environmental stability appears to control community stability. In the succession of a ditched stream after disturbance, the habitat and community diversity recover first while stability requires a longer period or may never be achieved as long as overlying unstabilizing influences persist on the watershed.

Since large-scale watershed modifications in the U.S. have continued for perhaps two centuries, it is now difficult to evaluate the extent to which stream communities have been altered. Larimore and Smith (1963) found considerable changes in the fish fauna in Champaign, County, Illinois in the past 60 years. The changes they found were associated with large-scale modification of watersheds. Recent deterioration of the Great Lakes fisheries has been tied to over-exploitation of fish populations and to massive deforestation and modification of the watersheds over the last century (Smith 1972).

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4.6 TILE DRAINAGE

4.6.1 Initial Tile Sampling Program

Approximately fifty percent of the Black Creek Watershed has subsurface drainage. This was determined by a tile monitoring program in 1974 which entailed each tile outlet in the watershed being located and sampled if flowing. Table 52 is a summary of this sampling program. Using an estimate of drained area per tile (based on its size) an estimate of 6000 Ac of drained land was obtained.

TABLE 52
Summary of Initial Tile Sampling Program

Ditch	No.# of Tile Outlets Located	No.# with Known Surface Drain Inlets	Tile Outlets Sampled
Black Creek	88	11	29
Dreisbach	126	16	36
Richeldfer	139	8	29
Gorrel	95	9	29
Wertz	85	--	49
Smith-Fry	81	--	12
Killian	69	--	10
Lake	21	2	7
Fuelling	43	--	0
Wann*	102	--	65
Total Black Creek only	747	46	201

*Not within Black Creek Watershed (adjacent)

The above tile samples were analyzed for sediment and nutrient concentrations. Table 53 provides the concentration statistics of all the collected samples. The water quality of the tiles were not significantly different between ditches except for the soluble nutrients (see Table 54). The Dreisbach and Richelderfer drains were very high in ammonia and soluble phosphorus but relatively low in nitrate. Wertz and Smith-Fry showed opposite characteristics. The high ammonia and soluble phosphorus levels are directly attributed to the high septic input (from Harlan) to the tiles in the Dreisbach and Richelderfer drains. The high nitrate levels in the Wertz and Smith-Fry drains result from the more intense row crop agriculture in these watersheds as compared to the other drains.

TABLE 53
Concentration of Sediment and Nutrients in Tile Effluent

Component	Range	Geo. Mean	Mean	S.D.
	mg/l			
Sediment	634	79	88	52.5
Ammonia	73	.63	2.33	7.9
Nitrate	43	5.9	8.95	7.3
Sol. Org. N	58	3.17	6.21	10
Sed. N	53	6.26	9.35	7.8
Sol Inorg. P	7.6	.02	.31	1.04
Sol Org. P	1.45	.01	.05	.14
Sed. P	13.5	.10	.56	1.75

TABLE 54
Sediment and Nutrient Concentrations by Ditch - 1974

	Mean Concentration (mg/l)							
Ditch	SS	Amm	Nit	SON	SED.N	IP	SOD	SED.P
Black Creek	101	2.7	9.8	5.9	6.3	.36	.06	.45
Dreisbach	101	9.8	7.5	4.2	8.3	1.3	.14	.80
Gorrel	84	.56	4.6	4.1	7.8	.05	.01	.08
Killian	91	.55	7.0	3.9	5.2	.06	.05	.05
Wertz	74	.51	10	3.2	12	.02	.02	.04
Smith-Fry	98	1.0	9.6	4.7	5.0	.15	.09	.16
Richelderfer	88	2.0	10	6.1	11	.19	.05	.22
Lake	110	5.8	6.0	26	7.4	1.0	.01	2.7
Wann*	86	.50	10	7.2	11	.12	.02	.87

*Not in Black Creek Watershed (adjacent)

No significant difference in sediment or nutrient concentration was observed between tiles of different flow. This is expected because the higher flows are achieved when larger areas are drained and not by a lateral system design or moisture difference. It should be noted that the sampling program took several weeks to complete, but the general area remained dry for the entire period.

4.6.2 Tile Monitoring Continued Program

After the analysis of the 1974 sampling program it was decided that tile effluent in Black Creek needed further study. The initial study did not provide for any time dependence within the data. Therefore, twenty representive tile outlets were selected for a continued monitoring program. Septic influence, flat and rolling land, intensity of farming, artesian water, size of drainage area, etc. were all considered.

This additional tile data served to verify the conclusions of the initial sampling program and also indicated some significant time dependent effects. The concentration of all sediment and nutrient components varied dramatically with time. A trend could not be determined for the concentrations of any component response to tile flow. Table 55 shows the R-squared values of the correlation study. It is obvious that the flow does influence concentration but not always in the same way. Table 56 shows the overall statistical results for two years of data for the twenty sites combined. The high range in the data is evidence of the flow effects. The high range in the 1974 data (initial study) is due to the variety of tiles, not flow.

TABLE 55
Values for Exponential Fit - Tile Flow and Sediment-Nutrient Components

Tile	R-Squared-Value							
Site	SS	Amm	Nit	TN	SN	IP	TP	SP
1	-.076	-.086	.029	-.005	-.010	-.049	-.044	-.046
2	.127	.004	.000	.026	-.020	.116	.187	.081
3	.004	.003	.000	.003	.000	.009	.056	.020
4	.083	.064	.050	.070	.056	.208	.195	.185
5	.030	.239	.131	.167	.166	.151	.310	.335
6	.090	.066	.014	.026	.019	.229	.225	.088
7	.118	.051	.013	.058	.020	.406	.253	.279
8	.014	.220	-.050	-.017	-.026	.385	.449	.553
9	-.025	.000	.106	.093	.121	.046	.456	.034
10	.009	.020	-.013	.000	.000	.010	.219	.013
11	.323	.053	.083	.015	.027	-.248	-.269	-.195
12	.004	.029	.018	.038	.019	.138	.156	.108
13	.033	.030	-.026	-.001	-.005	.545	.449	.522
14	-.001	-.022	.057	.002	.000	.077	.068	.093
15	-.017	-.009	.003	-.056	-.058	.000	.000	.000
16	.240	-.077	-.014	-.003	-.174	-.036	-.001	-.036
17	-.178	-.021	-.046	-.039	-.036	.037	.154	.031
18	.054	.158	-.001	.010	.000	.544	.502	.506
19	-.012	.065	.081	.067	.081	.201	.264	.089
20	.273	.013	-.106	.000	-.109	.409	.394	.112

Number of samples = 34/site

TABLE 56
Concentration of Sediment and Nutrients for 20 Tile Sites

Component	Range	Geo. Mean	Mean	S.D.
	mg/l			
Sediment	12,900	76	111	496
Ammonia	41	.35	1.70	4.85
Nitrate	49	6.16	8.72	6.80
Sol. Org. N	151	.07	.96	6.83
Sed. N	47	.31	.93	2.74
Sol Inorg. P	52	.03	.34	2.28
Sol Org. P	9.3	.03	.06	.37
Sed. P	39	.07	.37	1.90

4.6.3 Results of Automatic Tile Sampler

An automatic tile sampler was developed to help determine the time dependent relationships in tile flow. The data will also be helpful in the calibration of a tile flow model which is being developed (see Section 0.0.2).

The automatic tile sampler has been operational since March, 1976 on a 43 acre Hoytville soil. The tile drainage system is uniform with no surface inlets. The two years of record are for a below average tile flow period, because of the relatively low rainfall during late winter and early spring which is normally the high flow period for tiles. 1976 was the driest of the two years. Table 57 shows the results of the sediment and nutrient losses from the tile site. It is estimated that a more normal outflow figure would be between 5-10 cm/year. Note that in both years the nitrate losses greatly exceeded all other losses except for sediments.

TABLE 57
Sediment and Nutrient Losses from Tile Effluent - Automatic Sampling Site

Component	1976	1977*
	kg/Ha	
Sediment	20.5	53.9
Ammonia	.011	.27
Nitrate	.678	10.6
Sol. Org. N	.053	3.14
Sed. N	.112	.65
Sol Inorg. P	.002	.051
Sol. Org. P	.005	.019
Sed. P	.019	.141
Outflow	1.22 cm	6.91 cm
Rainfall	65.70 cm	45.50 cm

*Through 7/6/77

The concentration data did vary with flow but not as dramatically as some other tiles in the Black Creek Watershed. Sediment and nutrient components all tended to increase with increased flow. This response is not linear and tends to be more dramatic during the leading edge of a hydrograph then during the trailing edge (see Figure 17). An initial flashing action seems to be present. Flow vs. concentration correlation results are given in Table 58. Table 59 shows the average concentration of the tile effluent for the two years.

TABLE 58
R-Squared Values for the Automatic Tile Sampling Site

Variables		R-Squared			
Independent	Dependent	Linear Fit		Exponential Fit	
		1976	1977	1976	1977
Stage	SS	.676	.152	.715	.121
	Amm	.200	.336	.006	.304
	Nit	.809	.040	.866	.045
	TN	.801	.318	.830	.253
	SN	.798	.332	.841	.261
	IP	.611	.408	.538	.516
	TP	.860	.143	.886	.268
	SP	.538	.391	.544	.437
Flow	SS	.699	.182	.733	.145
	Amm	.179	.371	-.007	.325
	Nit	.802	.036	.840	.044
	TN	.795	.359	.806	.281
	SN	.784	.372	.809	.286
	IP	.632	.454	.545	.525
	TP	.866	.168	.867	.292
	SP	.524	.438	.522	.465
Sus. Solids	Amm	.104	.197	-.009	.148
	Nit	.611	-.004	.649	.002
	TN	.606	.203	.565	.141
	SN	.592	.184	.626	.113
	IP	.620	.328	.446	.169
	TP	.850	.353	.787	.366
	SP	.537	.330	.567	.203
No.# of Samples		47	180	47	180

* The R-squared values may be misleading because of times series dependence which exists in the data. It would be more realistic to assume the number of degrees of freedom to be less than fifteen which would yield a 5% significant level of R-squared = 0.3.

The field monitored is nearly flat and has raised field borders. This prevents any surface runoff and could be considered an ideal BMP for erosion control and soil conservation. Because of this unique situation, we were able to measure total field losses by simply monitoring the tile effluent. As a result of forcing all the water through the soil profile,

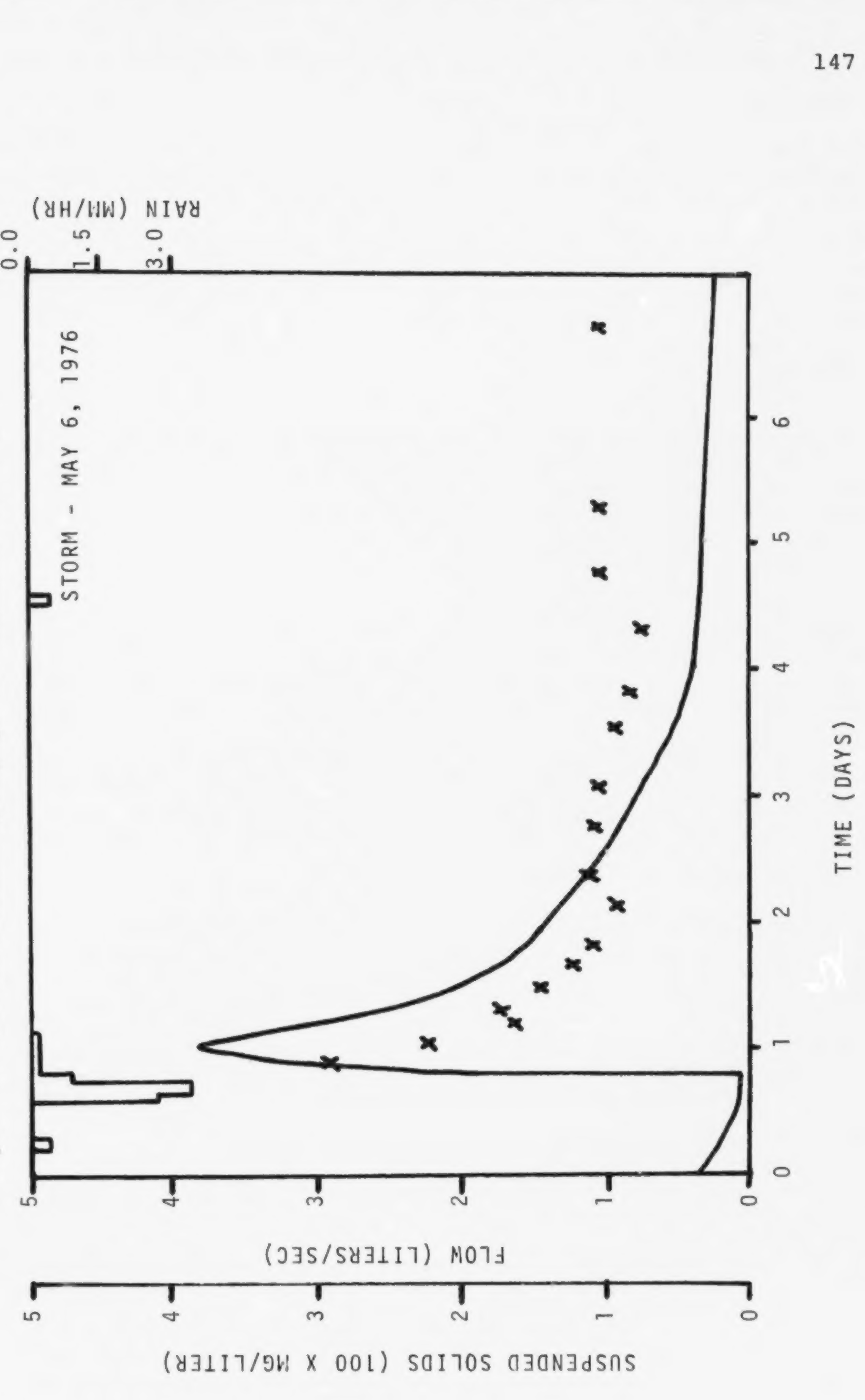


Figure 17. Flow and Sediment Hydrograph for Automatic Tile Sampler

TABLE 59
Concentration of Tile Effluent from Automatic Sampling Site by Year

Component	1976	1977*
	mg/l	
Sediment	170	78
Ammonia	.09	.38
Nitrate	5.6	15.3
Sol. Org. N	.44	4.5
Sed. N	.92	.93
Sol. Inorg. P	.02	.07
Sol. Org. P	.04	.03
Sed. P	.22	.20

*Through 7/6/77

sediment and nutrient losses were greatly reduced. This is due to both the reduced water loss and the reduced concentration of the nutrient and sediment, except for nitrate-N whose concentration would not necessarily decrease. However, the reduced water loss was much more significant than the change in nitrate-N concentration. See Table 57 (Also Table 0 in Section 0.0.0) for a comparison of results.

The amount of fertilizer nutrients lost was not large. The field monitored received amounts of fertilizer (180 kg/ha -N and 70 kg/ha -P) in excess of the Black Creek average. Even at this higher fertilizer rate, the annual losses of N and P as compared to the amount applied were less then 6 and .2 percent respectively for the wetter of the two years monitored.

The hydrologic response of the tile system on the Hoytville soil is very rapid. Peak flows occurred within 5 to 7 hours of all rain storms and generally returned to zero flow within a week. Deep cracking may be a contributing factor to this rapid hydrological response of the tile system.

4.6.4 Pesticide and Herbicide Response

Both insecticide and herbicide contamination was detected in the tile effluent shortly after a surface application of these chemicals. The insecticide used was Furadan and the herbicide used was Lasso II. The accumulative losses of Furadan and Lasso II per hectare were .014 and .003 kilograms respectively with the peak concentration in ppm reaching .213 and .042 respectively. Herbicide and pesticide losses were of the order of .1 percent of applied. The movement of these pesticides is due mostly to the deep cracking, which gives water an open channel to flow to the tiles.

4.6.5 Stream Grab Sampling Program

A stream grab sampling program was started in the Black Creek Watershed in March, 1973. Nineteen sites were selected for monitoring. (See Section 0.0.1.1.) The Maumee, St. Mary and St. Joseph rivers were among these selected sites. Samples are collected at least once a week at each site. Grab sites 2, 6 and 12 were monitored more intensively with the installation of an automatic pumping sampler.

The additional data obtained at sites 2 and 6 showed that the grab samples alone could not adequately describe the loadings of sediment and nutrients from the site's associated watershed. Grab samples alone greatly under predicted the annual loading for all sediment associated components. Soluble components were better described by the grab samples, but their associated error would still be high. Table 60 gives a quantitative view of the inherent weakness of a grab sampling at an interval greater than the time response of the watershed. The hydrological time response of the Black Creek Watershed is of the order of hours compared to a weekly sampling rate.

TABLE 60
Prediction of Loading From Complete Data Base

	Loading Prediction (kg/Ha)							
	Weekly Grab Only*				Complete Data File			
	Site 2		Site 6		Site 2		Site 6	
Component	1975	1976	1975	1976	1975	1976	1975	1976
Sus. Solids	572	178	869	142	2130	640	3740	380
Ammonia	1.21	.59	2.4	1.3	1.5	.60	1.8	.85
Nitrate	14	2.95	9.4	1.3	19.0	5.5	12.0	2.4
Sol. Org. N	1.4	.63	2.0	.88	1.7	.31	2.3	.53
Sed. N	3.2	.91	6.7	.75	31	3.9	28.0	2.8
Sol. Inorg. P	.09	.04	.26	.21	.14	.064	.34	.18
Sol. Org. P	.09	.04	.10	.04	.097	.034	.12	.040
Sed. P	.61	.20	1.4	.27	5.2	.98	4.5	.73

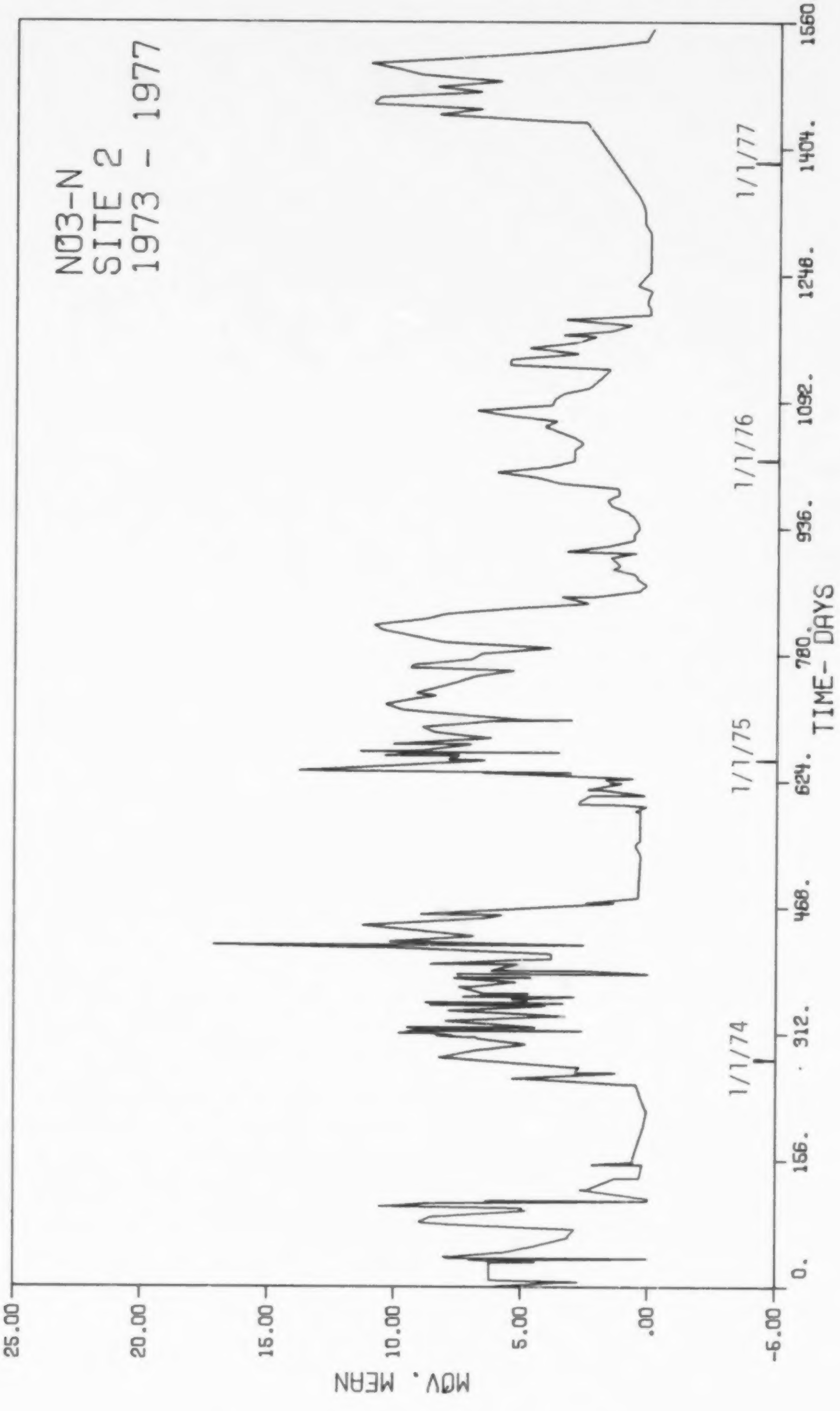
* Flow data for computation does use the complete flow record, not just that associated with the given grab sample.
Using the grab flow record only would cause even larger errors

A strong annual cycle existed for the concentration of nitrate in streams as seen in Figure 18. To a much lesser degree, the cycle also exists for ammonia. The nitrate and ammonia concentrations peaked during late winter or spring. The high percent of tile flow and fertilizer application during this period could account for some of the increase in nitrate levels. Also the biomass uptake of nitrogen would tend to lower the concentrations of both nitrate and ammonia in the summer months. Phosphorus and suspended solids showed no annual variation.

Correlation analysis of the grab and automatic pumping sampler data combined showed a positive correlation between flow and sediment associated components and also between suspended solids and sediment associated nutrients. The soluble nutrients are generally not correlated with either flow, stage or sediment. Table 61 gives a summary of the R-squared values from sites 2 and 6 for the years 1975-76. The low R-square values are indicative of the high degree of scatter observed in the data. Figure 19 shows a plot of stage vs. suspended solids. Similar scatter was observed for the nutrients. An exponential curve fit was also tried but did not significantly improve the R-squared values as see in Table 62. The low R-squared values also show that functional expressions would not well represent the data.

The correlation of the sediment and sediment-bound nutrients may be a little misleading because of strong time series dependence in the samples.

Figure 18. Nitrate Concentration vs. Time for Weekly Grab Samples



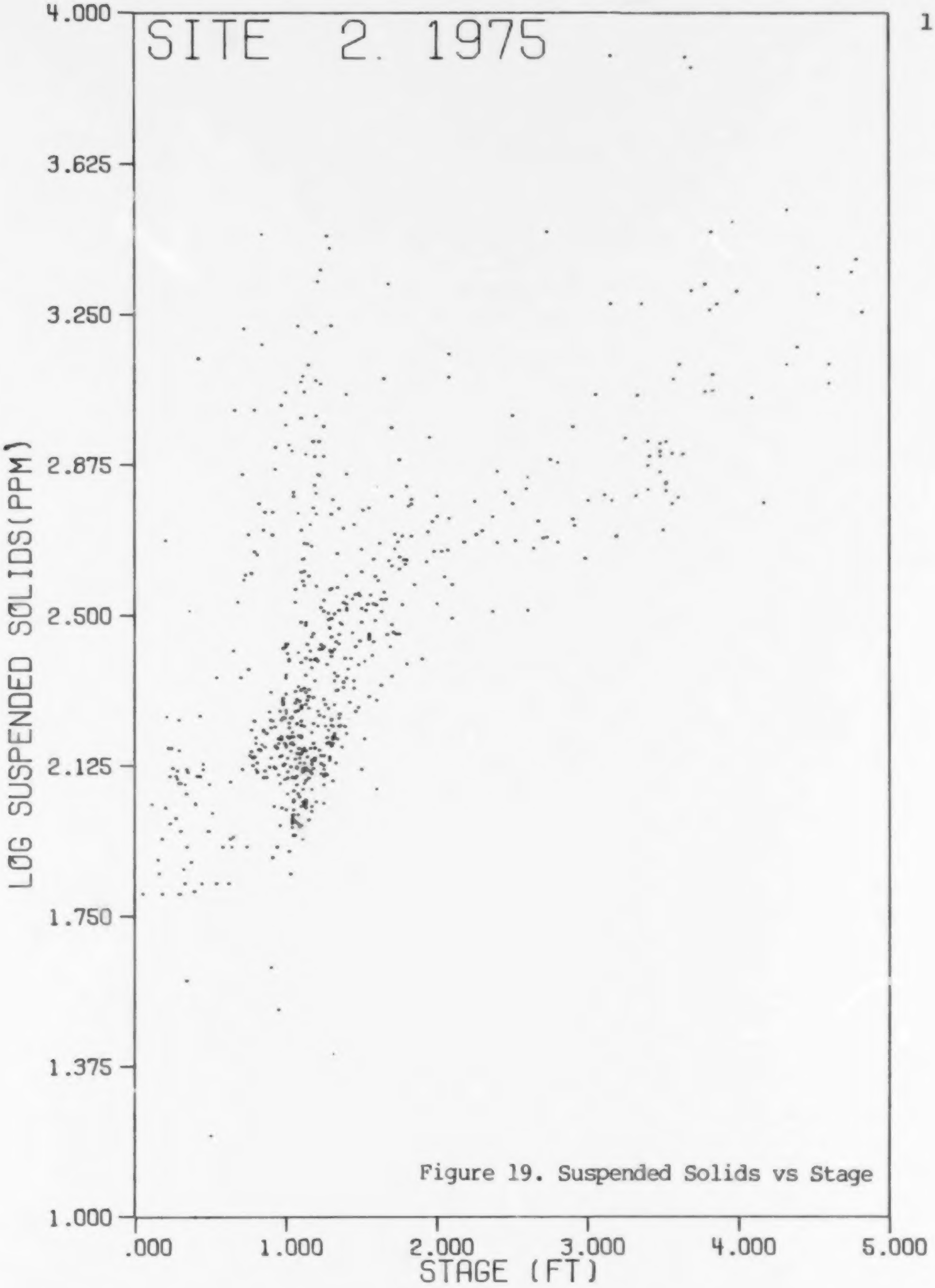


Figure 19. Suspended Solids vs Stage

A more realistic number of degrees of freedom would be 20 or less. If the different hydrological conditions of the watershed between the ascending and receding sides of the hydrograph were considered separately, an improvement is expected in the correlations. This is indicated by the two distinct scatter patterns in Figure 19.

4.7 TILLAGE STUDIES

It was predicted, prior to the undertaking of the Black Creek project, that alteration of tillage systems could have a significant impact on water quality in Black Creek and by extension in the entire Maumee Basin. These initial expectations were confirmed by simulated rainfall investigations during the project (see Section

The fact that water quality can be improved by tillage systems which increase surface cover and residue and which minimize moldboard plowing, does not guarantee that such systems will be economically feasible or that, if feasible, they will be voluntarily adopted by landowners in the Maumee Basin. The tillage studies undertaken in the Black Creek project had the dual purpose of investigating potential costs, yields, and profits of conservation tillage systems on the soils of the study area and of providing demonstrations of these tillage systems for area landowners.

Tillage studies were begun in 1974 on individual farms with the work conducted by the landowners. This procedure was not entirely satisfactory, as the experimental work often conflicted with regular farm operations on which the landowners were dependent for their livelihood. As a result, experimental work suffered. Beginning with the 1976 crop year, more traditional tillage investigations utilizing replicated plots farmed under closely controlled conditions were begun.

One of the original farmer-tillage demonstrations was carried on for three years, 1974-76. Yields were compared on three different soil types in this field. Average yields for the three years across all soils showed both chisel and disk tillage systems to be very competitive with either fall or spring moldboard plowing.

Five typical soil types were selected on which to perform replicated studies. Other areas were used as needed to obtain additional information. All study areas were fertilized and limed according to Purdue soil testing laboratory recommendations. Nitrogen was applied to the corn ground at the rate of 170 lbs actual N per acre, using 28 percent liquid nitrogen. Phosphorus and potassium were broadcast on all plots in the fall ahead of fall tillage every other year. Furadan was band applied for insect control on all corn plots. Herbicides were applied pre-emergence at planting. All chemicals, costs, and rates are reported later.

All 1976 tillage work was done in the spring due to late acquisition of the land and equipment. Primary tillage for the 1977 season was completed in the fall.

The corn hybrid used was Pioneer 3780, and the bean variety was Amsoy 71 in 1976 and Shawnee in 1977. Corn seeding rate was 24,000 per acre for all plots. Soybean seeding rate was 48 lbs/Ac for all plots. Corn yields were corrected to 15 1/2 percent moisture, and bean yields to 13 1/2 percent moisture.

Four tillage systems were investigated:

1. NO-TIL -- the only pre-plant activity was chopping the stalks.

2. CHISEL -- the soil was chisel plowed 8" to 10" deep and disked

once or twice prior to planting, as needed for a satisfactory seed-bed.

3. DISK -- two diskings to a 4" depth prior to planting were used with no primary tillage.

4. CONVENTIONAl -- the soil was moldboard plowed and disked twice before planting.

In 1976 corn was not cultivated, but all beans were cultivated, except the no-til plots. In 1977 all plots except no-til were cultivated. All tillage systems were repeated for corn after corn, corn after beans, and beans after corn. For the first year, 1976, the previous crop was the same for all systems. It was necessary to change row direction on two of the experiments. On these, early spring disking was necessary for the no-til plots in 1976.

Although replicated tillage comparisons were begun in 1976, the effect of previous crops on tillage success could not be determined until 1977 and is not included in this report. For corn, the three conservation tillage systems yielded as well as or better than conventional tillage on 4 of the 5 soils in 1976. Yields were not checked on Nappanee silt loam in 1976 due to extreme variation in the experimental area.

1977 corn harvest was not yet complete as this report was prepared. Yield data gathered so far shows all conservation tillage systems below conventional on poorly drained Hoytville and Nappanee soils. Corn yield with chisel tillage equalled conventional corn on better drained Whitaker and Haskins soils. (Data from Morley soils not yet available.)

Soybean yields were not significantly different among tillage systems in 1976 on upland Morley and Haskins soils. Disk and no-till soybean yields were slightly reduced on Whitaker loam and severely reduced on Nappanee silt loam. Increased phytophthora root rot with disk and no-till systems appeared to be the major cause of reduced yields.

Canada thistle, morning glory, and field bindweed were a problem in spots in the experimental areas but had little influence on yields.

In 1977, dry weather after planting caused reduced and delayed germination leading to more variation than usual in plant stands among treatments. Phytophthora root rot was much less severe than in 1976, but was again more prevalent in disk and no-till soybeans. Canada thistle, morning glory, and field bindweed were greater problems in 1977, were more difficult to control in soybeans than in corn, and were usually more severe with no-plow tillage systems.

In 1977 bean yields with all conservation tillage systems were greatly reduced on Hoytville and Nappanee soils, slightly reduced on Whitaker, and equal to or greater than conventional yields on Morley and Haskins soils.

Previous research in Indiana has identified the major factors which influence corn response to tillage.

These are:

a. Soil drainage -- the better drained the soil, the less tillage

TABLE 61
Linear Correlation Results for Sites 2 and 6

Variables		R-Squared Value			
		Site 2		Site 6	
Independent	Dependent	1975	1976	1975	1976
Stage	SS	.246	.175	.413	.191
	Amm	.000	.000	-.030	-.096
	Nit	-.030	.078	-.010	.050
	TN	.271	.264	.232	.187
	SN	-.028	.057	-.014	-.006
	IP	.013	.002	.023	-.028
	TP	.367	.272	.092	.173
	SP	.010	.004	.026	-.030
Suspended Sol.	Amm	-.001	-.064	-.007	-.023
	Nit	-.106	.000	-.078	.000
	TN	.333	.170	.349	.600
	SN	-.103	-.006	-.068	-.030
	IP	.033	-.063	-.018	-.064
	TP	.519	.276	.114	.570
	SP	.022	-.080	-.010	-.065
Flow	SS	.212	.164	.393	.247
	Amm	-.001	-.005	-.007	-.068
	Nit	-.075	.012	-.028	.010
	TN	.222	.127	.037	.173
	SN	-.072	.005	-.025	-.023
	IP	.001	-.001	-.006	-.047
	SP	.001	-.001	-.005	-.050
No.# of Samples		646	396	461	409

needed.

b. Previous crop -- shallow or no-tillage planting is more likely to be successful for corn in rotation.

c. Latitude -- shallow or no-tillage planting is more likely to be successful in areas with a longer growing season.

d. Pest control -- where weeds, insects and diseases cannot be adequately controlled with chemicals, no-plow tillage is not likely to be successful.

Research so far in the Black Creek study tends to support these points.

1976 and 1977 yield results are presented in the following tables. It should be noted that tillage systems must be evaluated over several years to accurately determine their success on different soil types.

4.7.1 Hoytville Silty Clay Loam

TABLE 62
Exponential Correlation Results for Site 2 and 6

Variables		R-Squared Value			
		Site 2		Site 6	
Independent	Dependent	1975	1976	1975	1976
Stage	SS	.439	.308	.617	.242
	Amm	.001	.002	-.012	-.073
	Nit	-.003	.188	.000	.097
	TN	.328	.349	.301	.241
	SN	-.007	.141	-.005	.000
	IP	.097	.042	.051	-.023
	TP	.466	.307	.429	.186
	SP	.041	.038	.046	-.022
Suspended Sol.	Amm	.000	-.046	-.006	-.025
	Nit	-.048	.072	-.030	.031
	TN	.384	.279	.430	.484
	SN	-.055	.024	-.041	-.012
	IP	.154	-.010	.035	-.062
	TP	.761	.338	.626	.398
	SP	.157	-.033	.045	-.073
Flow	SS	.295	.238	.218	.239
	Amm	-.004	-.003	-.007	-.081
	Nit	-.035	.045	-.018	.025
	TN	.189	.137	.035	.173
	SN	-.049	.025	-.019	-.013
	IP	.016	.013	-.004	-.040
	TP	.307	.190	.058	.149
	SP	.009	.009	-.006	-.043
No.# of Samples		646	396	461	409

TABLE 63
Corn Response to Tillage System

Tillage	Plants/Ac 1976	Plants/Ac 1977	Bu/Ac 1976(a)	Bu/Ac 1977
No-til(b)	21,500	8,500	134.9 b	92.0
Double disk	22,015	8,600	139.2ab	90.8
Chisel	18,937	11,200	144.1a	105.0
Plow	19,640	17,200	124.8 c	120.4

(a) Any yields followed by the same letter are not significantly different at the 10% level.
(b) These plots were disked once in 1976 to change row direction.

TABLE 64
Soybean Response to Tillage System

Tillage	Bu/Ac 1976(a)	1977
No-til(b)	31.8a	35.7
Double disk	32.4a	35.2
Chisel	31.5ab	33.4
Plow	28.3 b	40.4

(a) Any yields followed by the same letter are not significantly different at the 10% level.
(b) These plots were disked once in 1976 to change row direction.

Planting dates: Corn--May 5, 1976; Soybeans--May 25, 1976
--May 11, 1977 --May 25, 1977

This experimental area was in soybeans in 1975. In 1976, chisel provided highest corn yield and conventional the lowest, with shallow tillage intermediate. Conventional bean yields were also lowest in 1976. The conventional system was at a disadvantage on this soil because of the poor seedbed and delayed emergence associated with spring plowing.

In 1977 the situation was essentially reversed, with all no-plow systems having greatly reduced germination in the early season drought. Conventional tillage gave best stands and yields for both corn and soybeans.

4.7.2 Nappanee Silt Loam

TABLE 65
Corn Response to Tillage System

Tillage	Plants/Ac 1976	1977	Bu/Ac 1976	1977
No-til	19,000	16,000	No Data	76.6
Double disk	19,000	18,700	No Data	105.7
Chisel	20,625	19,500	No Data	111.2
Plow	20,000	21,800	No Data	126.6

The experimental area was in corn in 1975. Due to variation in drainage and nitrogen deficiency, no corn yields were taken in 1976. In 1977, stands with the conservation tillage systems were reduced slightly, for corn, but yield reductions were greater than would be indicated by stand losses on this very poorly drained soil.

Soybean yields with no-til and disk tillage were severely reduced in

TABLE 66
Soybean Response to Tillage System

Tillage	Bu/Ac 1976(a)	1977
No-til	7.8 c	28.5
Double disk	7.9 c	32.3
Chisel	17.2 b	36.7
Plow	29.8a	48.7

(a) Yields followed by the same letter are not significantly different at the 90% level.

Planting dates: Corn--May 11, 1976; Soybeans--May 25, 1976
--May 12, 1977 --May 20, 1977

1976. Yield with chiseling was intermediate between no-til and conventional. The same yield pattern occurred in 1977, but reductions were much less. Much of the yield loss appeared to be due to phytophthora root rot. This disease is known to be more damaging in poorly aerated soils, but the great difference in infection related to tillage depth was surprising.

4.7.3 Whitaker Loan

TABLE 67
Corn Response to Tillage System

Tillage	Plants/Ac 1976	1977	Bu/Ac 1976(a)	1977
No-til(b)	29,843	19,100	142.9	131.2
Double disk	20,953	19,800	145.7	145.7
Chisel	20,859	22,300	150.3	153.7
Plow	14,937	23,200	142.6	155.6

(a) Yields were not significantly different at the 90% level.
(b) Plots were disked once in 1976 to accomodate change in row direction.

This experimental area was in soybeans in 1975. There was no significant difference in corn yield among tillage treatments in 1976, but no-til yields were reduced in 1977. Shallow seed placement in 1977 no-til plots led to delayed germination, the most likely cause of yield loss.

Deep tillage, plowing and chiseling apparently improved soybean yields in 1976 and no-til yields were also reduced in 1977. Again, phytophthora

TABLE 68
Soybean Response to Tillage System

Tillage	Bu/Ac 1976(a)	1977
No-til(b)	34.2 c	42.0
Double disk	39.8 b	45.6
Chisel	41.1ab	44.3
Plow	44.8a	48.8

(a) Yields followed by the same letter are not significantly different at the 90% level.
(b) Plots were disked once in 1976 to accomodate change in row direction.

Planting dates: Corn--April 23, 1976; Soybeans--May 21, 1976
--May 10, 1977 --May 26, 1977

root rot appeared to contribute to these yield losses.

This is one of the better drained soils in the watershed and is a soil where we would expect disk and no-til yields to be competitive with deep tillage for corn. There is insufficient experience to make similar predictions for soybeans.

4.7.4 Morley Silt Loam

TABLE 69
Corn and Soybean Response to Tillage System

	Corn, 1976(a)		Soybeans, Bu/Ac	
Tillage(b)	Plant/Ac	Bu/Ac(c)	1976(c)	1977
No-til	20,281	91.1	23.2	35.1
Chisel	18,812	89.5	21.7	30.1
Plow	17,609	88.2	24.3	29.1

(a) 1977 corn plots were not harvested when this report was prepared.
(b) Due to a space limitation the disk treatment was omitted at this site.
(c) Yields were not significantly different at the 90% level.

Planting dates: Corn--May 13, 1976; Soybeans--May 27, 1976
--May 17, 1977 --May 23, 1977

The 1975 crop at this site was corn. Yield differences for both corn and soybeans were not significant in 1976. No-til bean yields were highest in 1977. It is important to note that conservation tillage systems were equal to plowing on this erosive soil.

4.7.5 Haskins Loam

TABLE 70
Corn Response to Tillage System

Tillage	Plants/Ac 1976	Plants/Ac 1977	Bu/Ac 1976(a)	Bu/Ac 1977
No-til	21,156	16,500	121.9a	110.8
Double disk	20,453	20,400	105.8 b	118.7
Chisel	21,000	21,200	111.7 b	126.7
Plows	20,500	22,600	111.5 b	129.0

(a) Yields followed by the same letter are not significantly different at the 90% level.

TABLE 71
Soybean Response to Tillage System

Tillage	Bu/Ac 1976(a)	Bu/Ac 1977
No-til	24.0	43.3
Double disk	24.4	43.5
Chisel	20.8	46.5
Plow	25.7	44.5

(a) Yields not significantly different at the 90% level.

Planting dates: Corn--May 12, 1976; Soybeans--May 27, 1976
--May 16, 1977 --May 23, 1977

Corn was grown in this experimental area in 1975. No-til corn yield was better than other systems in 1976, showing less drought stress in midsummer. Moisture conserved by the surface residues was important during this period. In 1977, no-til stand and yield were both lower than for other systems for corn. There was little difference among tillage systems in soybean yield in either year.

4.7.6 Chemicals Applied to Replicated Plots

The following chemicals and rates were used both years. Prices used were typical retail prices in the area.

TABLE 72
Costs for Chemicals, Corn and Soybean

For corn	Cost for plows, chisel, disk	Cost for no-til
Aatrex 4L, 1 qt/Ac @ 4.08/qt	$4.08	$4.08
Bladex 4L, 1 qt/Ac @ 4.00/qt	4.00	4.00
Lasso, 2 qts/Ac @ 3.87/qt	7.74	7.74
Furadan, 10#/Ac @ .76/lb	6.70	6.70
Paraquat, 1 pt/Ac @ 4.99/pt		4.99
Total	$22.52	$27.51
For soybeans		
Lorox, 2#/Ac @ 3.70/lb	7.40	7.40
Lasso, 2 qt/Ac @ 3.87/qt	7.74	7.74
Paraquat, 1 pt/Ac @ 4.99/pt		4.99
Total	$15.14	$20.13

4.7.7 Tillage Demonstrations

This continuous corn tillage trial on the Roger Ehle farm was one of the original farmer-cooperator demonstrations started in 1974. Although not replicated, the trial is interesting because the tillage plots cross three soil types in the same field, and because the years ranged from very dry (1974), to very wet (1975), with 1976 being closer to "average."

Yields from the soil types reflect the differences in seasons. Response to tillage is not so clear-cut. Two things stand out in the data. First, fall chisel yields were as good as, or better than, other systems across all conditions. And, second, no-til yields tended to be less under all conditions. We cannot fully explain the no-til response. Surface residue systems are usually more successful on droughty soils such as Oshtemo.

TABLE 73
Corn Response to Tillage, Roger Ehle Farm, Bu/Ac

	Rensselaer CL l.			Whitaker l.			Oshtemo FSL			3 Year Average All Soil Types
	74	75	76	74	75	76	74	75	76	
No-Til	128	115	125	81	129	101	27	137	93	104
Disk, Spring & Fall	187	138	164	94	152	116	30	159	96	126
Fall Chisel	184	143	162	111	164	122	54	166	102	134
Fall Plow	118	137	-	80	143	-	64	167	-	-
Spring Plow	168	139	161	72	151	134	21	166	90	122

In 1976, corn was planted into standing red clover 8"-10" in height, an intercrop from the previous year's wheat. Soil types were Haskins and Morley silt loam. Planting date was May 20 and final population was 19,500/Ac. Fertilizer applied was the same as for replicated plots. The following chemicals were applied at planting:

TABLE 74
Chemicals Applied at Planting

Aatrex 4L, 1.2 qt/Ac @ 4.08/qt = $4.90
Bladex 4L, 1.2 qt/Ac @ 4.00/qt = 4.80
Lasso, 2.4 qt/Ac @ 3.87/qt = 9.29
Paraquat, 2 pts/Ac @ 4.99/pt = 9.98
Furadan, 10#/Ac @ 0.67/lb = 6.70

Stand was reduced in several places in the demonstration due to rodent damage. The legume growth was greater than is recommended for no-til sod planting. Either taking an early hay crop or chemically killing the sod when about four inches in height would have allowed easier coulter penetration and provided less cover for rodents. Machine harvest of this four-acre demonstration yielded 98.2 bu/Ac, about equal to conventionally tilled corn in the area. Stress symptoms were much less severe in the sod-planted corn during summer drought.

Corn was no-til planted in soybean stubble in 1976. This was a seven acre demonstration near one of the replicated tillage experiments, with chemicals and fertilizer applied as in the replicated study. Corn was planted on April 22 on erosive Morley and Haskins silt loam soils. The machine harvest yield was 102.9 bu/Ac. The demonstration was quite successful, with an excellent stand and good weed control.

4.8 SOCIO-ECONOMIC STUDIES

Socio-economic studies in the Black Creek Watershed involved the collection of primary data from farmers in the watershed in order to determine changing attitudes of farmers toward soil conservation practices and to determine the cost of alternative soil conservation practices. The diversity of soil types, farm sizes, cultural situations and management practices in the watershed provided information on a variety of farming situations. The following material summarizes the approach of the study, the survey instruments used for data collection, the model design and results.

The approach to the sociological portion of the study involves analysis of those factors which influence the decision of the farmer to adopt conservation practices. These factors are related to those aspects of the Black Creek Project which are policy instruments which can be altered to influence the rate and extent of adoption of conservation practices.

The approach to the economic portion of the study includes analysis of the economic gain or loss to individual farmers that results from utilizing alternative conservation practices rather than currently prevalent methods of crop production. The results for the individual farmer are aggregated to determine the relative cost of instituting alternative conservation practices in the watershed.

Since data were needed from the farmers in the watershed, a survey instrument was prepared to obtain these data. The instrument was employed at two different time periods two years apart. This was necessary to obtain estimates of the changes in attitudes of farmers toward conservation during the operation of the project. The data were obtained for the survey instrument by personal interview of farmers in the watershed.

The model design of the study is divided into two sections. One section describes the model used in sociological research while the second section describes the model used in the economic research.

4.8.1 Model: Sociological

The questionnaires which were administered (in 1974 and 1976) were designed to measure characteristics of the farming operation, as well as various social, psychological, and economic characteristics of the farmer, including his attitudes toward pollution, government and toward the project itself. The specific variables used in this study are described below:

X1 Education (EDUCA) is the level of education completed by the farmer in actual years.

X2 Socio-economic status (SES) is the gross annual income of the farmer, in dollars, plus the total number of acres in his farm.

X3 Perceived need for innovation (NEED) is an index of 8 questions aimed at assessing the farmer's perception of the adequacy and effectiveness of pollution control efforts prior to the project. The lowest value possible was 8 and the highest possible was 32.

X4 Off-farm employment (OFFFARM) is measured by the percent of the farmer's 1973 family income which came from his off-farm employment.

X5 Leadership score (LEADER) is the actual number of sociometric choices the farmer received when respondents were asked who was a well-respected farmer in the area.

X6 Ethnic group (ETHGRP) is a dichotomous variable which indicates whether the farmer is Amish or Non-Amish. It is coded (1) for Amish and (2) for Non-Amish.

X7 Advice from leader (ADVICE) indicates whether the farmer has sought advice about farming practices from the person he selected as a well-respected farmer -- referred to here as "LEADERS", the variable representing community leadership. It is coded (O) for "no" and (1) for "yes".

X8 Agency Contact (AGENCYCT) is an index of the amount of contact the farmer has had with each of the agencies involved in the project during the past year. For each agency the actual number of contracts was coded unless the number exceeded four. The scores for each agency are then summed to yield a total score for each farmer.

X9 Knowledge of the project (KNOW) is an index of two questions indicating whether the farmer had knowledge of the project and was familiar with its intentions as of January, 1974. It is scored from (0) for no familiarity to (4) for much familiarity.

X11 Participation in the project (TAKEPART) indicates whether and to what extent the farmer has participated in the project as of March 1976. It is measured by an index of 2 questions designed to measure the farmer's perception of how much he had participated in the project since its inception.

These variables, along with their means and standard deviations, are presented in Table 75. They are presented as they fit the stages of the Black Creek Model in Figure 20.

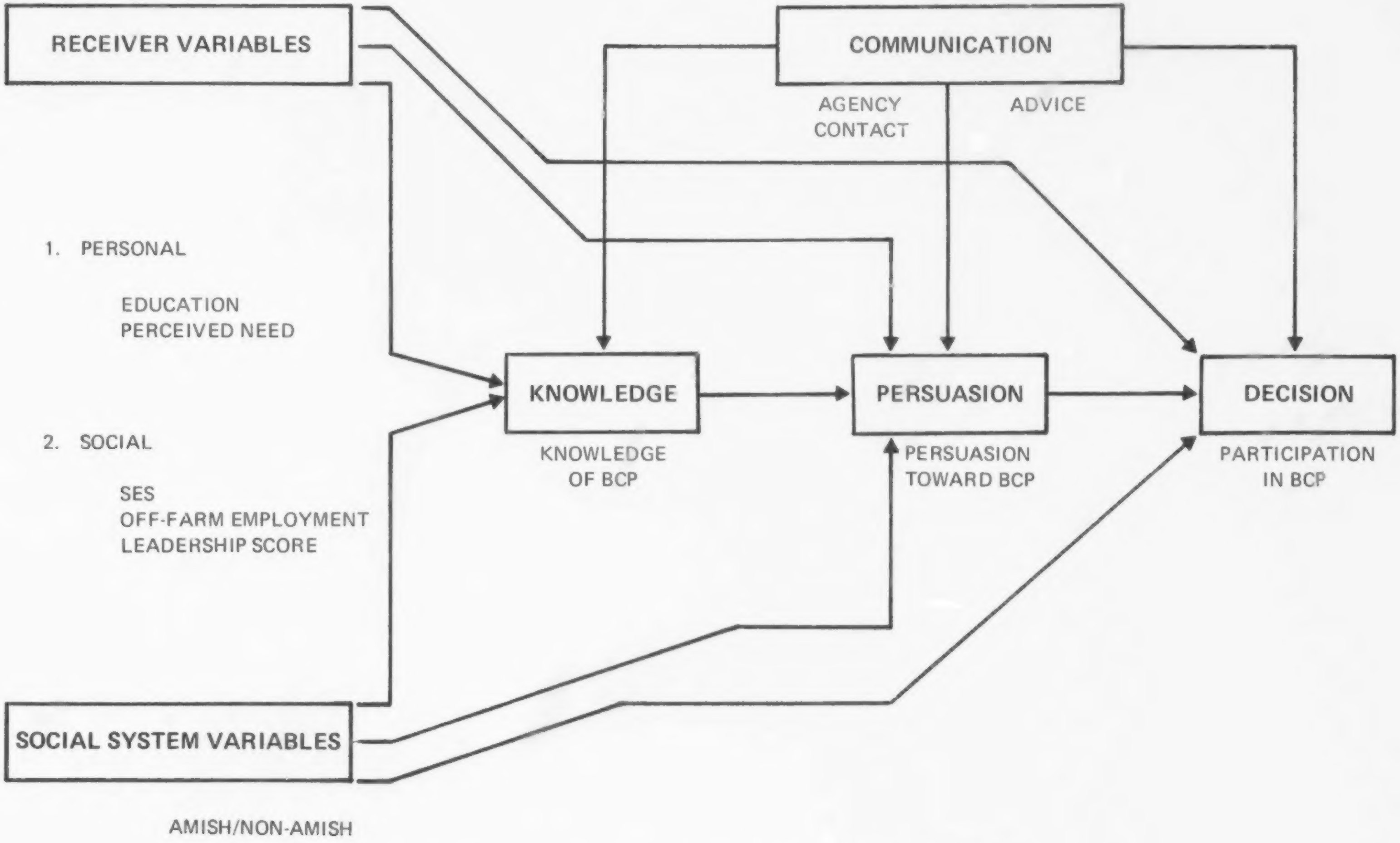

RECEIVER VARIABLES
1. PERSONAL
EDUCATION
PERCEIVED NEED
2. SOCIAL
SES
OFF-FARM EMPLOYMENT
LEADERSHIP SCORE
SOCIAL SYSTEM VARIABLES
AMISH/NON-AMISH
COMMUNICATION
AGENCY CONTACT
ADVICE
KNOWLEDGE
KNOWLEDGE OF BCP
PERSUASION
PERSUASION TOWARD BCP
DECISION
PARTICIPATION IN BCP

Figure 20. Black Creek Sociological Model

TABLE 75
Sociological Model Variables

Variable		Mean	Standard Deviation
X1	Education of the farmer	9.573	3.285
X2	Socio-economic status	20275.281	12411.972
X3	Perceived need for innovation	27.225	5.011
X4	Off-farm employment	77.494	104.067
X5	Leadership score	2.528	6.455
X6	Amish or Non-Amish	1.640	.483
X7	Advice from leader	1.337	.475
X8	Agency contact	6.006	7.969
X9	Knowledge of the project	2.989	.805
X10	Persuation toward the project	14.584	6.210
X11	Participation in the project	8.325	3.254

4.8.2 Model: Economic

A linear programming model was formulated to create a static equilibrium cropping plan. The model maximizes profit by selecting the most profitable combinations of crops and tillage practices while complying with resource constraints. Proper timing of operations and resource availability was specified in the land preparation, planting, and harvesting phases of production for each tillage practice. The four primary tillage practices were moldboard plow, chisel plow, double disking, and no-tillage preparation (see Table 76). The importance of timeliness in modern crop production is built into the model by adjusting yields to correspond to planting and harvest dates. In addition, cropping operations are specified to insure proper sequence.

TABLE 76
Primary Tillage Practices

Operation	Tillage Practice 1	Tillage Practice 2	Tillage Practice 3	Tillage Practice 4
Moldboard plow	X			
Chisel		X		
Disk or Field Cultivate	X	X	X	
Disk			X	
Plant	X	X	X	
No-till Plant				X

The analysis was conducted on four sets of data. These data sets correspond with: (1) a 580 acre farm with less than an average two percent land slope, (2) a 370 acre farm with less than average two percent land slope, (3) a 580 acre farm with greater than an average two percent land slope, and (4) a 370 acre farm with greater than an average two percent land slope.

The model solutions for each data set were examined at several levels of soil loss which constrained the productive activities below levels permitted in the optimal unconstrained solution. The results of the modeling process were evaluated at selected prices for the crop output. For example, the model solutions were compared for wheat prices at both $3.20 per bushel and $2.46 per bushel. The results were further evaluated for policy alternatives which either eliminated fall tillage or prohibited the use of the moldboard plow.

The analysis was performed first for the individual farm data sets to examine the change in the crop management practices and subsequent changes in net returns to labor and management. From these results, costs of each policy alternative were aggregated to represent modern crop management in the Black Creek Watershed.

The land, labor, and machinery resources of the two hypothetical farms used in this study were based on representative findings obtained in a survey of modern operations in the Black Creek Watershed. Model coefficients pertaining to labor, machinery, and time resources used in crop production were calculated according to procedures outlined in publications pertaining to crop budgeting (Brink _et al_. 1976, Doster _et al_. 1976). These calculations used labor and machinery information taken from a survey of the watershed and secondary data pertaining to rates of land, labor, and machinery use (Doster _et al_. 1976). Product prices and production cost estimates also came from secondary sources (_Agricultural Prices_, 1974).

Estimates of soil losses from agricultural cropland in the Black Creek Watershed were derived from the Universal Soil Loss Equation (Ohio CES, 1975). Crop management and yield information for these calculations was obtained from both agricultural data collected in the survey of the watershed and the secondary information concerning soil characteristics and crop production. Yield differences associated with different tillage practices were based on previous studies (Mannering _et al_. 1976, Griffith _et al_. 1973). Similarly, secondary information showed that different tillage practices cause different amounts of soil loss (Mannering _et al_. 1976, Griffith _et al_. 1973).

4.8.3 The Data Base

Computer coefficients which specify the resource requirements per acre are given in Table 77 and Table 78. A descriptive sample of the calculations used to derive these coefficients and a reprint of the field and labor time requirements chart from the Purdue Crop Budget Model B-93 (Doster _et al_. 1976) are given in Appendix B. Field rates from this chart were used to insure consistency among field and labor time requirements.

Coefficients that specify wage rates are based on figures used in the 1976 Purdue Crop Budget Model B-93 and were $4.00 an hour for labor hired in and $2.00 an hour for labor hired out of the operator's own crop activities. Part-time labor is assumed to be only 80 percent as efficient as the

TABLE 77
Computer Coefficients - 370 Acre Farm

	Labor Requirements (Man per field hours/acre/hour)	Field Preparation Hours per Acre-Fall	Field Preparation Hours per Acre-Spring	Field Planting Hours per Acre	Tractor Field Hours per Acre		Harvest Field Hours Available per Acre
Corn Preparation							
Till #1	.6486	.3093	.1833		.6521		
Till #2	.5097	.2062	.1833		.5221		
Till #3	.4516		.1833		.4673		
					Plant	Cult.	
Corn Production							
Till #1	1.1812			.1993	.1993	.1325	.3545
Till #2	1.1812			.1993	.1993	.1325	.3545
Till #3	1.1812			.1993	.1993	.1325	.3545
					Harvest = .3333		
Soybean Preparation							
Till #1	.4507	.3093	.1833		.4418		
Till #2	.3477	.2062	.1833		.3388		
Till #3	.2896		.1833		.2840		
Till #4							
					Plant	Cult.	
Soybean Production							
Till #1	.9494			.1993	.1993	.1325	.2146
Till #2	.9494			.1993	.1993	.1325	.2146
Till #3	.9494			.1993	.1993	.1325	.2146
Till #4	.9023			.1586	.1586	.1325	.2146
					Harvest = .3233		
Wheat Production							
Till #1	1.2579	.3093			.6180		.4000
Till #2	1.1549	.2063			.5150		.4000
Till #3	1.0968	.1667			.4507		.4000
Till #4	.7912	.1586			.5586		.4000

TABLE 78
Computer Coefficients - 580 Acre Farm

	Labor Requirements (Man per field hour/acres/hour)	Field Preparation Hours per Acre-Fall	Field Preparation Hours per Acre-Spring	Field Planting Hours per Acre	Tractor Field Hours per Acre		Harvest Field Hours Available per Acre
Corn Preparation							
Till #1	.5452	.1415	.1500		.5035		
Till #2	.4688	.1031	.1500		.4487		
Till #3	.3007		.1500		.1057		
					Plant	Cult.	
Corn Production							
Till #1	1.1812			.1057	.1057	.1325	.3545
Till #2	1.1812			.1057	.1057	.1325	.3545
Till #3	1.1812			.1057	.1057	.1325	.3545
					Harvest - .3333		
Soybean Preparation							
Till #1	.3832	.1415	.1500		.3535		
Till #2	.3037	.1031	.1500		.3388		
Till #3	.2037		.1500		.1997		
Till #4							
					Plant	Cult.	
Soybean Production							
Till #1	.9494			.1057	.1057	.1325	.2146
Till #2	.9494			.1057	.1057	.1325	.2146
Till #3	.9494			.1057	.1057	.1325	.2146
Till #4	.9023			.1586	.1586	.1325	.2146
					Harvest - .3333		
Wheat Production							
Till #1	1.2216	.1415			.4722		.4000
Till #2	1.1140	.1031			.4653		.4000
Till #3	1.0259	.1072			.3663		.4000
Till #4	.7912	.1586			.3586		.4000

operator's or full time labor.

Based on Information contained in Farm Planning and Financial Management (USDA, 1975), machine operation direct cost per acre is assumed to be $18.00 for corn, $8.75 for soybeans, and $6.25 for wheat. Indirect machinery and equipment costs per acre are assumed to be $24 for corn, $20 for soybeans, and $10 for wheat. Indirect machinery costs are deducted from the objective function value only after the basis has been determined and are used in calculating returns to labor and management.

Based on a land capability analysis of the Black Creek Study Area as given in Table A-3 of the Environmental Impact of Land Use on Water Quality (A Work Plan), two slope categories for the watershed can be developed. The first category includes all the land capability units with land slopes less than two percent. Of the 12,038 acres in the watershed, 6,293 definitely fit this class. The other more erosive category, land capability units with slopes greater than two percent, includes 2,047 acres. The II W-2 land capability unit is characterized by land with slopes from zero to two percent as well as land with slopes from two to six percent. The types of soils in the watershed characterized by these two ranges in slope are equally divided. Thus, the 3,698 acres in the II W-2 capability group were assumed to be equally divided between the two slope categories. This resulted in 8,142 total acres, or 68 percent of the watershed acres, being categorized as less than a two percent slope. The remaining 3,896 acres, or 32 percent of the watershed, are assumed to have slopes greater than two percent.

For the purposes of this study, an estimated 7,500 acres of cropland are characterized by modern management practices. The estimated 5,100 acres with land slopes less than two percent are assumed to have a universal soil loss equation length slope (SL) factor of .128. The 2,400 acres with greater than two percent slopes are assigned an SL factor of .6. The importance of land slope to this study becomes apparent from the following discussion of the universal soil loss equation.

Soil loss coefficients are derived from calculations based on Wischmeier and Smith's Universal Soil Loss Equation (Wischmeier et al. 1972).

Table 79 shows the average annual soil loss coefficients that correspond to the various tillage practices, crop rotations, crop management factors, and two length-slope (LS) factors that are associated with the given soil type. Soil losses were specified to correspond with common three year combinations of crop rotations and tillage practices.

Corn yields are assumed to average 118 bushels, soybeans average 42 bushels and wheat averages 52 bushels. Variations in yields and moisture correspond to different planting and harvesting dates. Table 80 presents these variations.

Corn yields are reduced for delays in planting at 1 bushel/acre/day from May 10 to May 23, and 2 bushels/acre/day from May 24 to June 6 (Doster et al. 1972). A two percent harvest field loss is assumed between the first and second harvest periods and a three to six percent loss between the last two periods. Similar yield penalties exist for soybeans. In addition to planting and harvesting dates, corn and soybean yields are affected by tillage practices.

Corn yield variations for soil types similar to those located in Black

TABLE 79
Average Annual Soil Loss Coefficient

Three-Year Base Combination[a,b]	Crop Management Factor (C)	Three Year Average Annual Soil Loss (Tons/Acre)	
		LS = .128	LS = .6
CTP1-CTP1-SBTP1	.3519	2.365	11.086
CTP2-CTP2-SBTP2	.1720	1.155	5.414
CTP1-SBTP1-SBTP1	.1362	2.931	13.739
CTP2-CTP2-SBTP2	.1720	1.155	5.414
CTP1-CTP1-SBTP3	.2368	1.591	7.459
CTP1-SBTP1-WTP1	.3000	2.017	9.450
CTP2-SBTP2-WTP2	.1320	.887	4.159
CTP1-SBTP3-WTP3	.1501	1.008	4.725
CTP1-CTP1-SBTP1	.3519	2.365	11.086
CTP2-CTP2-SBTP2	.1720	1.155	5.414
CTP1-CTP1-SBTP3	.2368	1.591	7.458
CTP1-SBTP1-SBTP1	.4362	2.931	13.739
CTP2-SBTP2-SBTP2	.1694	1.125	5.273
CTP1-SBTP3-SBTP1	.3204	2.153	10.092
CTP1-SBTP4-SBTP1	.3204	2.153	10.092
CTP1-WTP1-SBTP1	.3000	2.016	9.450
CTP2-WTP2-SBTP2	.1320	.887	4.159
CTP1-WTP3-SBTP3	.1501	1.008	4.725
SBTP1-SBTP1-WTP4	.1549	1.041	4.880
CTP1-CTP1-WTP1	.2227	1.497	7.017
CTP2-CTP2-WTP2	.0952	.640	3.000
CTP1-CTP1-WTP3	.2328	1.564	7.331
CTP1-SBTP1-WTP1	.3000	2.017	9.450
CTP2-SBTP2-WTP2	.1320	.887	4.159
SBTP1-SBTP3-WTP1	.1549	1.041	4.880
SBTP1-SBTP4-WTP1	.1549	1.041	4.880
SBTP1-WTP1-WTP1	.2234	1.515	7.102
SBTP2-WTP2-WTP2	.0847	.555	2.602
SBTP3-WTP3-WTP1	.0847	.555	2.602
SBTP3-WTP4-WTP1	.0847	.555	2.602

[a] C = Corn
SB = Soybeans
W = Wheat

[b] TP1 = Tillage Practice 1
TP2 = Tillage Practice 2
TP3 = Tillage Practice 3
TP4 = Tillage Practice 4

Refer to Table 3.1 for explanation.

TABLE 80
Average Corn Yield and Moisture Coefficients

Harvest Period	Tillage-Planting Treatment	Production Item	Planting Period April 26 to May 2	 May 3 to May 9	 May 10 to May 16	 May 17 to May 23	 May 24 to May 30
Sept 27 to Oct 17	TP1	Corn Yield	121	121	114		
		Moisture Points[a]	1210	1452	1596		
	TP2	Corn Yield	109	109	102		
		Moisture Points[a]	1090	1308	1428		
	TP3	Corn Yield	108	108	101		
		Moisture Points[a]	1080	1298	1414		
Oct. 18 to Nov. 7	TP1	Corn Yield	119	119	112	105	98
		Moisture Points[a]	595	838	1008	1260	1568
	TP2	Corn Yield	107	107	100	94	88
		Moisture Points[a]	535	749	900	1128	1408
	TP3	Corn Yield	106	106	99	94	90
		Moisture Points[a]	530	742	891	1128	1440
Nov. 8 to Nov. 28	TP1	Corn Yield	117	117	110	103	86
		Moisture Points[a]	468	585	668	824	1056
	TP2	Corn Yield	105	105	98	92	56
		Moisture Points[a]	420	525	588	736	946
	TP3	Corn Yield	104	104	97	92	80
		Moisture Points[a]	416	520	582	736	968

[a] Moisture points above 14 point base = moisture points above base x bushels/acre.

Creek were estimated based on conversations with Mannering and Griffith.

Similarly, reductions in soybean yields are assumed to occur when moldboard preparation is replaced. Adoption of chisel or double disc preparation is assumed to cause a five percent reduction in yield and no-tillage planting is assumed to cause a 10 percent reduction. Soybean production activities and corresponding yields are also presented in Table 81.

TABLE 81
Average Soybean Yield

Harvest Period	Tillage Planting Treatment	Item	May 3 to May 9	May 10 to May 16	May 17 to May 23	May 24 to May 30	May 31 to June 6
Sept. 13 to Sept. 26	TP1	Soybean Yield	43	43			
	TP2	Soybean Yield	41	41			
	TP3	Soybean Yield	41	41			
	TP4	Soybean Yield	39	39			
Sept. 27 to Oct. 17	TP1	Soybean Yield	41	41	40	38	34
	TP2	Soybean Yield	39	39	38	36	32
	TP3	Soybean Yield	39	39	38	36	32
	TP4	Soybean Yield	37	37	36	34	30

Elevator drying costs for corn are taken from the Purdue Crop Budget B-93 and are assumed to be \$.16 per every ten moisture points dried down. Fertilizer, insecticide, herbicide, and credit and miscellaneous costs are presented in Table 82.

Original product prices are assumed to be \$2.30 per bushel of corn, \$5.50 per bushel of soybeans, and \$3.20 per bushel of wheat. Based on the survey findings, land market value was assumed to be \$1,500 per acre. Interest in land at eight percent per acre and an \$8.00 change per acre for taxes and land maintenance were taken from Farm Planning and Financial Management (USDA, 1975). Thus, \$128.00 per acre is deducted from the objective function value when returns to labor and management are derived.

The right-hand-side values of the linear program specify the resource limit. the number of productive acres for any one crop was never allowed to exceed 2/3 of the total available acreage. This permitted the use of a three-year crop rotation. The right-hand-side value for the soil loss constraint equalled the sum of the allowable soil loss per acre multiplied by the number of acres.

STUDY RESULTS

TABLE 82
Production Costs

Item	Costs per Acre of Production[a] Corn	Soybean	Wheat
Fertilizer	$44.00	$12.00	$34.00
Insecticide	7.00	0	0
Herbicide	11.00	13.00	0
Seed Cost	11.00	8.00	12.00
Credit & Miscellaneous	8.00	6.00	5.00

[a] Based on cost figures contained in Purdue Crop Budget Model B-93, p. 9-12.

4.8.4 Sociological Conclusions

The sociological model has several implications for government projects which attempt to introduce innovations, in terms of understanding the process of developing participation and adoption among farmers, and the role that the project agencies and informal social relationships play in this process.

To a large extent, the model indicates that agencies played their principal role in simply informing farmers about the project. Farmers who knew about the project tended to develop a favorable attitude toward it. This is important, because it means that it is not necessary to coerce farmers to participate in projects of this nature.

Another important implication of the model is indicated by the sizeable affect of ETHGRP at all three stages of the process. The model also indicates that the Amish are more likely to have a higher level of knowledge, greater favorability, and more participation, than the non-Amish. It is recognized that the project and its subsidies provide special circumstances for the adoption of environmental practices, and there are several specific considerations worth noting.

(1) The Amish have a very integrated, effective communication system within their community, so that if contacts are made with only a few Amish

farmers, many of them will know about it in a very short time. This is very different from the situation among the non-Amish, where farmers tend to know fewer of their neighbors, have less frequent contact with them, and would be less likely to inform others.

(2) The Amish might also have been more likely to have received knowledge of the project early (in 1974) because their land was generally poorer and had more erosion problems. Thus, they would have been more likely to have been contacted by project personnel than non-Amish, who are situated on better land, have larger farms and higher SES.

Farmland and its surrounding roads constitute over 590 million acres of land in the United States, of which about 387 million acres are cropped (Seneca et al., 1974). This farmland borders on virtually all major water sources. Given this immense amount of land, it is readily apparent that agricultural pollution could affect all major waterways in this country.

The type of effort represented by the Black Creek Project provides a way for area farmers to become involved in decision making. It gives them an opportunity to discuss agricultural options open to them with their neighbors. Farmers who share their opinions on certain issues can work together to help speed solutions to their problems.

The project also provides farmers with an opportunity to work together to help solve a problem of national significance. By participating in this project they can make an effective contribution to the reduction of pollution, while only slightly reducing their profits from farming. This is particularly true in the present case due to the existence of the subsidies for those adopting the innovations.

Because of this, the outlook for continuation of innovations by area farmers after withdrawal of cost-sharing is good. Furthermore, the generally favorable reaction reported by the farmers to the project should serve as a positive indication that many farmers are quite willing to accept and use technological innovations if they are made available and their benefits are carefully explained. The high level of participation in the project among the Amish is a particularly good sign in this respect.

Although the long term effects of the Black Creek Project on the farmer's attitudes and behavior will not be known for several years, the conclusion that the existence of the project led to a voluntary alteration of behavior and attitudes by farmers in the area is inescapable. This is consistent with much of the research using behavior modification, which has found that one way to modify behavior is to offer explicit rewards in early stages, but that in many cases after a sufficient period of time the rewards for the modified behavior become implicit, so that the behavior will continue even after the explicit rewards are no longer provided.

It should also be noted that this research can be used to illustrate the major role which technological innovations can play in generating social development in rural areas. By initiating community meetings and encouraging participation in decision-making the existence of a project such as the Black Creek Project is also likely to lead to an increase an individuals' involvement in the affairs of the local community.

4.8.5 Economic Conclusions

Analysis of the results show that far less than proportional amounts of sediment come from the relatively flat, less erosive, crop land. Based on the unconstrained optimal solutions to the hypothetical farms, only 31 percent of the soil loss from modern crop production came from 68 percent of the total acres. Therefore, primary emphasis of controlling soil loss should be placed on those acres with steeper slopes where, according to the analysis, 69 percent of the watershed's soil loss from modern crop production came from only 32 percent of the acres.

At the unconstrained optimal solutions, farmers prepared corn and soybean land in the fall with the moldboard plow. One-third of the acreage was put into corn production while two-thirds went into soybeans. As the soil loss constraints on the steeper land slopes became more restrictive, tillage practices tended to shift from moldboard preparation to increasingly greater amounts of chisel preparation (see Table 83).

TABLE 83

Net Revenue, Returns; Slopes Greater Than Two Percent

Farm Size (Acres)	Soil Loss Tons/Acre	Net Revenue Per Acre	Acres of Corn Preparation Moldboard	Acres of Corn Preparation Chisel	Acres of Soybean Preparation Moldboard	Acres of Soybean Preparation Chisel
580	12.8a	$177.62	197		383	
580	10	175.55	0	197	325	58
580	8	172.90	0	197	185	198
580	6	170.25	0	197	45	338
580	4	166.[illegible]4		342		238
370	12.8a	179.89	123		247	
370	10	177.77	0	123	208	39
370	8	175.12	0	123	119	128
370	6	172.47	0	123	30	217
370	4	166.34		230	0	140

a -- Soil loss is unconstrained.

Results of restricting the use of moldboard plow preparation indicate the same crop production patterns as in the unconstrained optimal solutions. However, corn and soybean preparation was performed with a chisel plow on all of the 370 acres and most of the 580 acres. Double disking was used for some soybean preparation on the 580 acre farm.

Overall the larger farm seemed to show greater flexibility in complying with the policy constraints on fall preparation and the use of moldboard preparation than the smaller farm. At least the economic impacts, in terms of costs per acre when fall preparation was constrained and cost per ton of reduced soil lost when moldboard tillage was constrained, were less severe for the larger farm. A comparison of a soil loss constraint policy with a crop management constraint policy revealed that the same amount of soil loss could be achieved at a lower economic cost when soil loss constraints are implemented. The flexibility to select the most appropriate crop management combination for a particular farm and sediment problem allows more timely operations and higher revenues. For example, achieving a specified level of soil loss by restricting the use of a moldboard plow has a higher cost per acre than achieving that level of soil loss without restricting the use of the moldboard plow.

4.8.6 Policy Implications

The control of nonpoint agricultural water pollution in general, and soil losses in particular, will have a significant impact on crop management. According to this study, sediment reduction can more efficiently be achieved by policies that constrain soil loss than by policies that constrain crop management practices. However, the application of a uniform soil loss constraint policy would more severely affect operators on more erosive land. Since these soils are generally less productive anyway, the disparity between these and better, less erosive land would only be increased. Consequently, operators on the more erosive, steeper sloping land would likely suffer greater economic impacts from (1) changes in crop management that cause reduced yields or less profitable crop rotations, and (2) a further decline in relative land values.

The exclusive reliance on crop management practices to meet the more restrictive soil loss constraints would have negative economic consequences. Other methods of control, such as structural remedies, i.e. terraces, holding ponds, and field borders, should be assessed to supplement changes in crop management. However, even with alternative control methods, soil loss reduction on more erosive land would have to be subsidized for these operations to remain at a competitive profit level with larger farms on flat land.

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4.9 MODELING

4.9.1 ANSWERS

Planning is a process of evaluating the relative effectiveness and costs of alternative courses of action designed to attain stated goals. One of the most effective methodologies appropriate for planning non-point source pollution control programs is known as simulation. This approach utilizes a mathematical model of the system under consideration to evaluate the consequences of alternative control strategies.

The validity of pollution control programs developed using the simulation approach is entirely dependent upon the accuracy with which the model can predict the effectiveness of the control strategies being considered. Therefore, a model capable of accurately simulating a wide range of alternatives is essential if this approach to planning is to be successful. One major effort of the Black Creek Project was the development of a comprehensive model designed to characterize the behavior of natural watersheds during storm events and to evaluate the impact of alternative land use practices on water quality.

In selecting a structure for an agricultural non-point source pollution model, the pollution control planning process was characterized as a two-stage effort. The first step, as evidenced by the current efforts in 208 planning agencies, was considered to be an assessment phase. The budgetary and time constraints and the magnitude of the task precluded any other approach. This assessment phase is a process of determining the relative magnitude of the pollution problems and identifying the primary geographic regions requiring urgent attention, *i.e.* one of setting priorities.

The second stage of non-point source planning can be defined as an implementation phase. During this phase, planning decisions will be required concerning expenditures of funds to achieve effective treatments. This involves the application of specific treatments to individual, small land units. In order to be economically viable and politically acceptable, these planning decisions must be accurate and applied with great selectivity to only those areas which will yield significant improvements in water quality.

With these considerations in mind, project personnel decided to develop a model designed to be of general usefulness to the second phase of 208 planning. The result was a distributed parameter model called ANSWERS, Areal Non-point Source Watershed Environment Response Simulation.

A distributed parameter watershed model is one which incorporates the influences of the spatial variation of controlling parameters, *e.g.* topography, soil types, vegetation, etc., in a manner internal to its computational algorithms. In contrast, the more commonly employed lumped model approach is one which incorporates, to whatever degree they are not ignored, these effects by an *a priori* analysis on a case by case basis. In other words, the lumped approach uses some type of averaging technique to generate an "effective" coefficient(s) for characterizing the influence of specific non-uniform distributions of each parameter. The influence of this distribution is then represented by the "lumped" coefficients, and the resulting model is treated as a mathematical transformation of input into output, *i.e.*, a "black box," for the subsequent simulation.

A primary advantage of a distributed parameter analysis is its potential for providing a more accurate simulation of natural catchment behavior. The term potential is used because increased accuracy is by no means a direct consequence of using a distributed analysis; rather, it is realized only if the model is designed to take advantage of removing the constraints imposed by lumped parameters.

Lumped models almost invariably employ some weighting function to account for the spatial variability of watershed parameters, such as soil type, cover and slope steepness. Such weighting functions, regardless of how elaborate, are applied to the catchment prior to modelling runoff. This constrains the parameter values to be independent of the magnitude and temporal distribution of the storm event. Such a constraint is valid only for linear systems. Thus, the assumptions and limitations of behaving, at least to some degree, as a linear system are subtly imposed on lumped models.

Another linear system assumption implicit to almost all weighting functions used with lumped models results from ignoring the influence of geographic placement of spatially varying factors within the catchment boundaries. The magnitude of error associated with such approximations has been demonstrated by Huggins, et al. (1973).

A second major advantage of a distributed model is its inherent ability to simultaneously model conditions at all points within the watershed. This readily permits the simulation of processes that change both spatially and temporally throughout the catchment. The accuracy with which interacting processes can be modelled is thereby increased. In addition, a great deal more information about the simulated process is available to planners.

Finally, distributed models greatly facilitate incorporation of relationships developed from small scale "plot-size" studies to yield predictions on a watershed scale. It is much easier to formulate the individual processes being modelled as independent equations applicable at a point, letting the subsequent model integration process incorporate effects of spatial and temporal variability, than to develop an elaborate weighting function for each process. This approach also directly accounts for process interactions that would otherwise be ignored or require complex modifications of weighting functions.

The development of a comprehensive watershed model such as ANSWERS can be subdivided into a number of steps or phases. A useful subdivision consists of three stages to model building: conceptualization, definition of quantitative (mathematical) component relationships, and verification. Model concepts determine what is required in the way of component relationships and define the ultimate accuracy limits of the model. The process of developing component relationships for the various parameters included in a model is generally an iterative one. In other words, the verification process is used to modify and refine the component relationships of the model. Ultimately, the accuracy and generality of the resulting model are limited by the adequacy of model concepts and the availability of field data to validate various component relationships incorporated into the model.

Initial concepts of a distributed parameter watershed model were reported by Huggins and Monke (1966) and by Huggins, et al. (1973). That work was restricted to predicting runoff hydrographs, although the unique applicability of the approach as a framework for non-point source pollution models was noted, Huggins, Podmore and Hood (1976). Beasley (1977) greatly expanded this basic hydrologic model to incorporate tile inflow, channel flow routing and the most important aspect of non-point source pollution from cropland, soil erosion. Henceforth it became known as the ANSWERS model. Beasley utilized the GASP simulation language, with its inherent implicit solution algorithms, to code the original version of the ANSWERS model. Dr. J. R. Burney developed a much improved method of incorporating channel flow effects, included the ability to study spatially and/or temporally variable rainfall and refined the infiltration and soil erosion relationships used in the model. He also recoded the model using FORTRAN in order to obtain a major reduction in the amount of computer memory required and some improvement in execution speed. This version of the model employs an explicit integration algorithm. The detailed structure of the ANSWERS model, developed under the Black Creek Project, is presented below.

4.9.1.1 MODEL CONCEPTS

ANSWERS is a deterministic model based upon the fundamental hypotheses that:

> "At every point within a catchment a functional relationship exists between the rate of surface runoff and those hydrologic parameters which influence runoff, e.g., rainfall intensity, infiltration, topography, soil type, etc. Furthermore, these surface runoff rates can be utilized in conjunction with appropriate component relationships as the basis for modelling other transport-related phenomenon such as soil erosion and chemical movement within that watershed."

An important feature of the above hypothesis is its applicability on a "point" basis. In order to apply this approach on a practical scale, the point concept is relaxed to refer instead to a watershed "element". An element is defined to be an area within which all hydrologically significant parameters are uniform. Of course, this process of going from a point to an elemental area could be extended indefinitely until one assumed the entire watershed was composed of a single element with "averaged" parameter values, i.e., a lumped model. The actual geometric size of an element is not critical because there is no finite-sized area within which some degree of variation in one or more parameters does not exist. The crucial concept is that an element must be sufficiently small that arbitrary changes of parameter values for a single element have a negligible influence upon the response of the entire catchment.

A watershed to be modelled is assumed to be composed of elements, square in shape for computational convenience, with all hydrologic parameters being uniform within each element. Parameter values are allowed to vary in an unrestricted manner between elements; thus, any degree of spatial variability within the watershed is easily represented. Individual elements collectively act as a composite system because of supplied topographic data for each element delineating flow directions in a manner consistent with the topography of the watershed being modelled. Element interaction occurs because surface flow (overland and channel), flow in tile lines and groundwater flow from each element becomes inflow to its adjacent elements. In all other respects, the elements are hydrologically independent.

Mathematically, individual elemental responses are combined into a watershed system response by integration of the continuity equation:

$$I - Q = \frac{dS}{dt} \qquad (1)$$

where:
I = inflow rate to an element from rainfall and adjacent elements,
Q = outflow rate,
S = volume of water stored in an element,
t = time.

This equation may be solved when it is combined with a stage-discharge relationship, e.g. Manning's equation.

For the watershed model to be complete, it is necessary to incorporate component relationships for the remaining hydrologically significant processes which influence runoff and any related pollutants. Specific forms of relationships included have no effect whatsoever on the integration algorithm or distributed model concepts. However, relationships chosen have a marked impact upon the accuracy with which the model can characterize real watershed behavior. The significant consequence is that to substitute one component relationship for another when subsequent research on component processes develops improved relationships is a relatively trivial task.

Hydrologic processes for which quantifying component relationships must be developed are shown qualitatively in Figure 21. After rainfall begins, some is intercepted by the vegetal cover until such time as the interception storage potential is met. When the rainfall rate exceeds the interception rate, infiltration into the soil begins. Since the infiltration rate decreases in an exponential manner as the soil water storage increases, a point may be reached when the rainfall rate exceeds the combined infiltration and interception rates. When this occurs, water begins to stand on the surface in micro-depressions.

Once surface retention exceeds the capacity of the micro-depressions, runoff begins. Water accumulated in order to produce flow across the surface is surface detention. Subsurface drainage begins when the pressure potential of the groundwater surrounding a tile drain exceeds atmospheric potential. A steady-state infiltration rate may be reached if the duration and intensity of the rainfall event are sufficiently large.

When rainfall ceases, the surface detention storage begins to dissipate until surface runoff ceases altogether. However, infiltration continues until depressional water is no longer available. Subsurface drainage continues as long as there is excess soil water surrounding the drains. The long recession curve on the outflow hydrograph, typical of tile drained areas, is then produced.

Soil detachment, transport, and deposition are very closely related to concurrent hydrologic processes in a watershed. Detachment and transport can both be accomplished by either raindrop impact or overland flow. Detachment by rainfall occurs throughout a storm even though overland flow may not occur. Thus, most of the soil particles detached prior to flow initiation are deposited and to some extent, reattached. Detachment of soil particles by overland flow occurs when the shear stress at the surface is sufficient to overcome the gravitational and cohesive forces of the particles. Whether or not a detached soil particle moves, however, depends upon the sediment load in the flow and its capacity for sediment transport.

The transport of chemical pollutants from a land area is also highly related to the hydrologic behavior of a catchment and, for certain chemicals such as phosphorus and cadmium, the soil erosion that occurs. These processes can readily be incorporated into a distributed model by developing component relationships for individual elements.

Natural rainfall events do not exhibit the steady appearance shown in Figure 21. Furthermore, uniformity of coverage over a watershed will usually vary during an event. In addition, hydrologic responses of various areas within a watershed may vary greatly. Hence, the resultant hydrograph for the entire watershed will contain at least some of the effects of all of these highly complex, unsteady, non-uniform interactions. For these reasons, a distributed model must be designed and utilized as a means of describing and quantifying these processes.

Every hydrologic or erosion component of the ANSWERS model is expressed as a rate. Thus, infiltration and interception rates can both be subtracted from the rainfall rate to provide the excess rainfall rate used in satisfying surface retention and detention. The difference between the inflow and outflow rates is integrated to provide a volume. When divided by the elemental area, this yields the average depth of water over an element. The depth, in turn, is used to determine an outflow rate by applying a runoff function that accounts for both runoff and detention.

The thrust of the project's modelling effort was the development of a new approach that could be used as a planning tool. Rather than devote

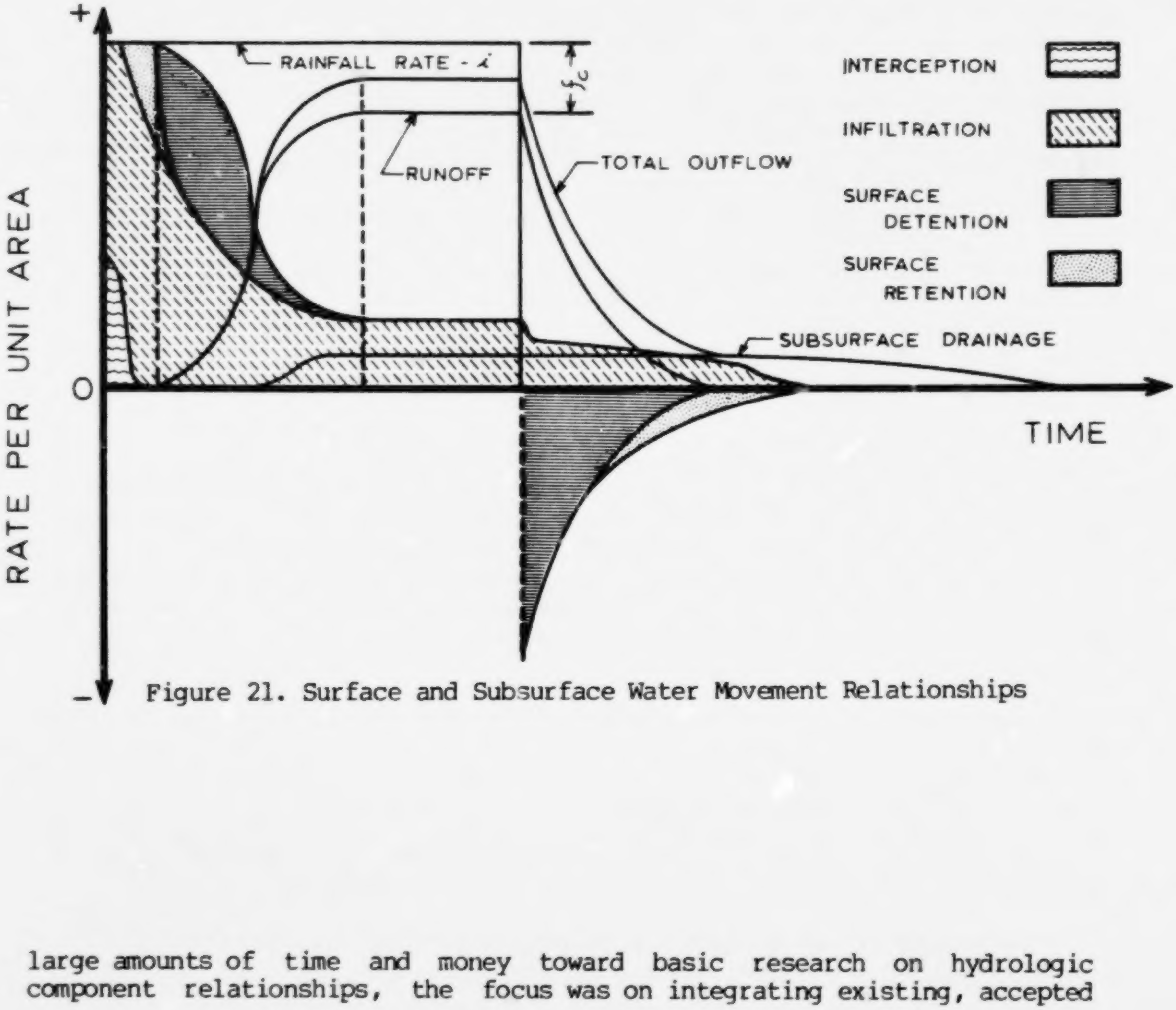

+
RAINFALL RATE - i
fc
RUNOFF
TOTAL OUTFLOW
INTERCEPTION
INFILTRATION
SURFACE DETENTION
SURFACE RETENTION
SUBSURFACE DRAINAGE
RATE PER UNIT AREA
0
TIME
–

Figure 21. Surface and Subsurface Water Movement Relationships

large amounts of time and money toward basic research on hydrologic component relationships, the focus was on integrating existing, accepted relationships into a simulation structure that had a high degree of versatility and reliability.

The specific component relationships selected for the current version of the ANSWERS model are outlined below. All were selected so that modularity was preserved. Modification or replacement of component relationships such as infiltration or erosion does not affect the computational algorithms of other components. In other words, the component relationships are sufficiently independent from each other that user-supplied subroutines may easily be substituted for those originally used in the ANSWERS model. This framework also permits users to append additional component relationships to simulate other processes important to specific applications.

4.9.1.2 COMPONENT RELATIONSHIPS

4.9.1.2.1 Flow Characterization

Within its topographic boundary, a catchment is divided into an irregular matrix of square elements, as shown in Figure 22. Each element acts as an overland flow plane having a fixed slope and direction of steepest descent. Channel flow is analyzed by a separate pattern of channel elements (referred to hereafter as channel segments), which underlie the grid of overland flow elements. Elements designated to have channel flow may, therefore, be viewed as dual elements. These elements act as ordinary overland flow elements, with the exception that all overland flow out of that element goes into its "shadow" channel segment. Flow out of a channel segment goes into the next downslope channel segment. This downslope channel segment will also receive flow from any other channel segments which flow into it and from its own overland flow element.

Overland and tile outflow from an element is assumed to be proportioned as separate surface and tile line inflow into adjacent row and column elements according to the direction of the slope of the element. The slope direction is designated on input as the angular degrees counterclockwise from the positive horizontal (row) axis. For the example shown in Figure 23 below, slope direction is in the fourth quadrant. The slope direction angle equals 270 degrees plus angle "a".

The fraction of outflow going into the adjacent row element, RFL, is:

$$RFL = \frac{\tan(a)}{2} \qquad \text{if: } a \leq 45^{\circ}\text{, and} \tag{2}$$

$$RFL = 1 - \frac{\tan(90-a)}{2} \qquad \text{if: } 45^{\circ} < a < 90^{\circ} \tag{3}$$

with the remaining outflow going into the adjacent column element. Since everything, including surface slope, within an element is assumed to be constant, this method of partitioning overland flow seems intuitively obvious. Such is not the case for tile flow. In general, records are seldom available which delineate the layout of tile systems. However, limitations on feasible installation depths mean that tile slopes must, with only temporary deviations, follow the general topography. Therefore, the use of an element's slope properties would seem to be a close

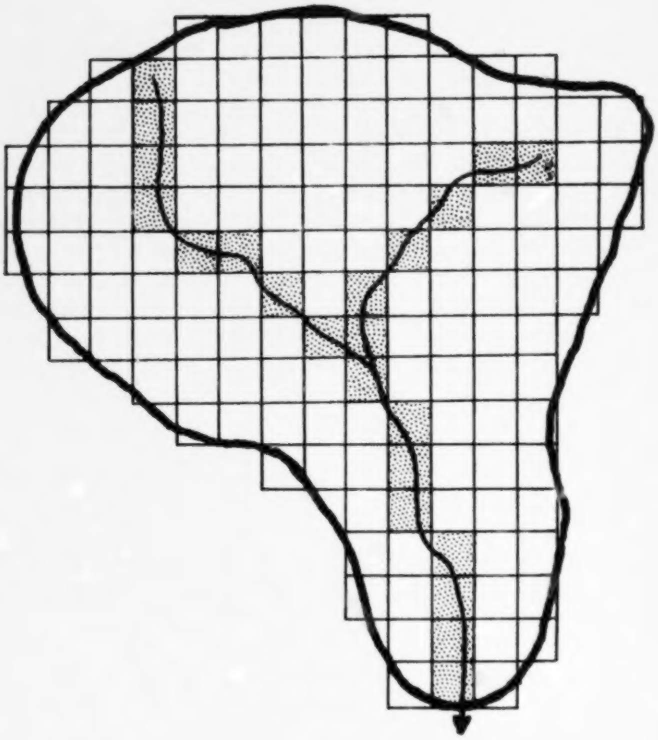


Figure 22. Watershed Divided into Element with Channel Elements Shaded

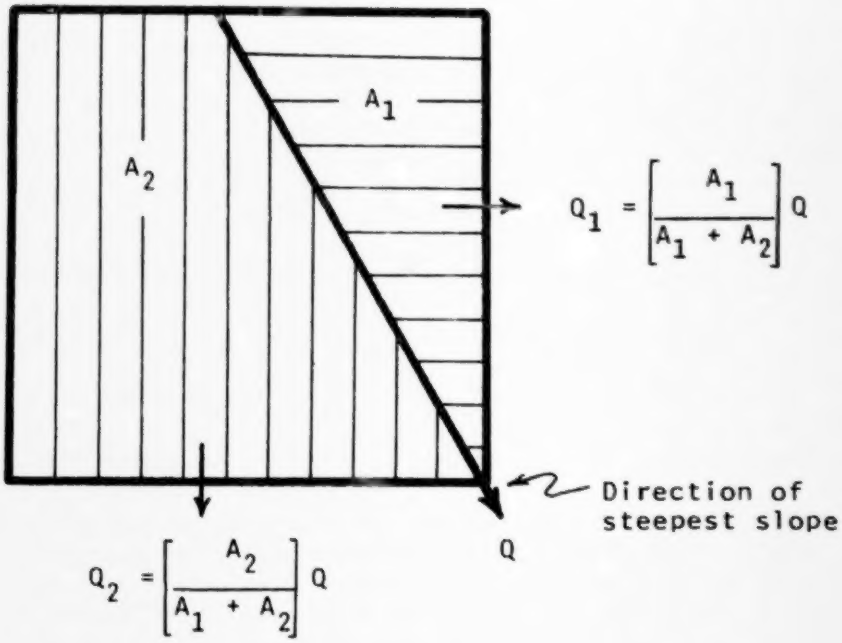

A_1
A_2
$Q_1 = \left[\frac{A_1}{A_1 + A_2}\right] Q$
Direction of steepest slope
Q
$Q_2 = \left[\frac{A_2}{A_1 + A_2}\right] Q$

Figure 23. Partitioning of overland flow.

approximation which eliminates the need for additional input information.

The flow relationship utilized in conjunction with the continuity equation to perform the overland flow routing is Manning's equation. The hydraulic radius is assumed equal to the average detention depth in an element. Detention depth is calculated as the total volume of surface water in an element, minus the retention volume, divided by the area of the element. This implies that the entire specified retention volume of an element be filled before any water becomes available for surface runoff.

Although the channel system is unrestricted in direction and branching, it is necessary that it be continuous and that each element contain only one channel segment. To achieve greater definition it is necessary to assume a smaller element size for all elements, with a consequent increase in core storage and execution time.

As all flow leaving the overland section of a dual element is constrained to enter the channel segment, the slope direction of a dual element is irrelevant in terms of division of outflow. However, the slope direction is of vital importance in establishing channel continuity. All outflow from a channel segment enters an adjacent channel segment located in one of the eight directions of the cardinal axes or the diagonals. The specific direction is determined by the slope direction assigned to the dual element. This slope direction must be within 22 degrees of the direction of the intended receiving channel segment, and in view of the above it is recommended that only 45 degree increments in slope direction be specified for dual elements.

It is permissible to specify the slope, width and Manning's roughness coefficient for each channel segment independent of the corresponding values for its overland flow element. Typically, rather than having a unique set of values for each channel segment, they are grouped into reaches with similar coefficients. Manning's equation is again used as the flow relationship required, in conjunction with the continuity equation, to perform the routing calculations.

4.9.1.2.2 Interception

Interception encompasses the total volume of water removed from the incoming rainfall by raindrop contact with and retention by the vegetal canopy, and by evaporation during the storm event. The water retained by the vegetation, *i.e.*, interception storage, is held primarily by surface tension forces. This portion of the total interception is quickly satisfied, particularly in more intense storms. Since a dense vegetal cover can expose an immense surface area to rainfall, the amount of moisture evaporating from this exposed area can be considerable, even during high humidity conditions of a storm. However, for storm intensities of primary interest from the standpoint of non-point pollution from cropland, interception is a relatively minor hydrologic component. In order to reduce simulation costs, interception was assumed to be uniform in rate and total volume over each type of vegetation.

Horton (1919) did a great deal of work in the area of estimating the amount of and mechanisms controlling interception. He studied the water intercepted by several species of trees as well as some economically important crops. Values of from 0.5 millimeter to 1.8 millimeters of interception storage volume were found to exist for trees and nearly as much for well developed crops. Horton recommended the following relationship as a means of describing the interception for a particular event:

$$V = A(B + CP)h \tag{4}$$

where:
V = interception volume per unit area -- mm,
P = precipitation -- mm,
h = height of crop -- m,
A, B and C are constants depending on the type of vegetal cover.

The constants referred to above are listed for several crops in Table 84. The B coefficient is a measure of the interception potential of the crop. The C coefficient attempts to describe evaporation potential.

TABLE 84
Interception Constants Recommended by Horton

Crop	A	B	C
Oats	3.3	.18	.07
Corn	h/3	.13	.005
Grass	7	.13	.08
Pasture and meadow	3.3	.13	.08
Wheat, rye, and barley	3.3	.13	.05
Beans, potatoes, and cabbage	.8h	.5	.15

4.9.1.2.3 Retention

Surface retention is a component that can have a pronounced effect on surface runoff and drainage characteristics of a watershed. Rough ground can store large amounts of water. Huggins and Monke (1966), using several field surfaces, developed a dimensionally homogeneous relationship describing the surface retention storage potential of a surface as a function of the water depth in the zone of micro-relief. The resulting relationship is of the form:

$$\frac{s}{su} = A\left(\frac{h}{hu}\right)^B \tag{5}$$

where:
s = volume of stored water,
su = hu times area of element,
h = height above datum,
hu = height of maximum micro-relief,
A and B are characteristic parameters.

In order for this equation form to yield a correct surface area as h approaches hu it is necessary that the product of A and B equal 1. Values of hu, A, and B for several field surface conditions, appear in Table 85.

TABLE 85
Typical Surface Storage Coefficients

Condition	hu--mm	A	B
Plowed Ground			
Spring -- smooth	100	.53	1.9
Spring -- normal	130	.48	2.1
Spring -- rough	130	.59	1.7
Fall -- smooth	60	.37	2.7
Fall -- normal	70	.33	3.0
Fall -- rough	130	.45	2.2
Disked and Harrowed			
Very smooth	30	.42	2.4
Rather rough	60	.43	2.3
Corn stubble	110	.59	1.7

4.9.1.2.4 Subsurface Waters

Currently, three subcomponents of subsurface water movement are incorporated into the ANSWERS model: infiltration, tile drainage and base flow. The effort devoted to modelling each roughly corresponds to their relative importance in simulating non-point pollution from cropland. Thus, infiltration processes are simulated in greater detail than tile flow while base flow is modelled only crudely.

Infiltration can greatly affect the hydrologic response of a watershed. Although many years of research have been conducted on infiltration phenomena, there is still no universally accepted method for describing infiltration on a watershed scale. The method chosen for the ANSWERS model was developed by Holtan (1961) and Overton (1964). In a dimensionally homogeneous form it can be expressed as:

$$f = fc + A\left(\frac{S - F}{Tp}\right)^{P} \qquad (6)$$

where:
f = infiltration rate at a particular time,
fc = final or steady state infiltration rate,
A = maximum possible infiltration rate,
S = storage potential of soil within the control zone (total porosity minus antecedent soil moisture),
F = total volume of water infiltrated,
Tp = total porosity within the "control depth",
P = dimensionless coefficient relating the rate of decrease in infiltration rate with increasing soil moisture content.

This form uses the soil water content, rather than time, as the independent variable. It is computationally advantageous when modelling with rainfall intensities less than the infiltration capacity and for simulating recovery due to drainage during brief periods without rainfall.

During periods of zero rainfall rate any infiltration which occurs must be supplied by the volume of water stored as either retention or detention. Since the surface of an element is seldom entirely inundated, the computed infiltration capacity is reduced in direct proportion to the percent of the soil surface not submerged. The area submerged for any given volume of water in an element can be computed by differentiating the relationship developed above to characterize surface retention.

Holtan's equation requires six infiltration parameters to be specified for a given soil type: total porosity, field capacity, depth of the control zone, steady-state infiltration rate (fc), and the two unsteady-state coefficients (A and P). Data from both large plot-sized simulated rainfall tests, Skaggs, et al. (1969) and field rainulator tests conducted in cooperation with USDA-ARS as a part of the Black Creek Project have been used to estimate parameter values. All of these tests indicated that surface crusting conditions have a major impact on the observed infiltration relationship. Experience with Holtan's equation has indicated the influence of crusting can be modelled by adjustment of the specified depth of the control zone. Crusting requires the use of a shallower control zone.

According to Holtan's conceptualization of the infiltration process, a "control zone" depth of soil determines the infiltration rate at the surface. He defined the depth of this control zone as the shallower of the depth to an impeding soil layer or that required for the hydraulic gradient to reach unity. Extending this same concept somewhat, the ANSWERS model maintains an accounting of water that leaves this control zone.

The rate of water movement from the control zone is a function of the moisture content of that zone. The two conditions which can exist are handled according the following rules:

(1) when the moisture content of the control zone is less than field capacity, no water moves from this zone,

(2) when the control zone moisture exceeds field capacity, the water moves from this zone according to the equation:

$$Dr = fc\left(\frac{1 - Piv}{Gwc}\right)^{N} \tag{7}$$

where:

Dr = drainage rate of water from the control zone,

Piv = volume of water that could still potentially infiltrate into the control zone,

Gwc = gravitational water capacity of the control zone, i.e. total porosity minus field capacity,

N = parameter controlling rate of movement, usually assumed equal to 3.

This relationship satisfies the continuity requirement that at saturation, when Piv = 0, the drainage rate from the control zone equals the steady state infiltration rate, fc. In addition, it exhibits intuitively desirable properties of decreasing moisture movement rapidly as the soil dries from saturation and of asymptotically approaching a zero drainage rate.

Water leaving the control zone contributes to tile drainage, if the element is tiled, or to base flow. In both cases the water is assumed to re-emerge into the channel segments. Water moves from the infiltration control zone into the "pools" available for tile and/or base flow at a rate equal to Dr.

Individual elements may selectively be designated as being tile drained. In addition to water coming from the control zone, tile inflow may be occurring from adjacent tiled elements. The sum of these two rates constitutes the rate of subsurface inflow into an element. Subsurface water moves out the element's tile at this inflow rate up to a maximum outflow rate equal to the tile drainage coefficient. Whenever the rate of subsurface inflow to an element exceeds its drainage coefficient, that excess water is diverted to baseflow storage. Elements which are not tiled have a drainage coefficient of zero.

Subsurface water entering an element at rates in excess of its drainage coefficient is stored in a single "pool". To simulate base flow it is released directly into channel segments at a rate proportional to the volume of water in storage. The proportionality constant, referred to as the base flow release fraction, is specified in the input data file. Water is released at an equal rate to each channel segment. For small catchments having no defined channels, only overland flow will appear at the outlet. Base flow will be non-zero only for watersheds with channel segments.

4.9.1.2.5 Sediment Detachment and Movement

Soil erosion as it relates to non-point source pollution can be viewed as two separate processes, detachment of particles from the soil mass and transport of these particles into the streams and lakes. Detachment of either primary soil particles or aggregates can result from either rainfall or flowing water. These same factors can cause detached particles to be transported to the water supply network. Thus, there are four processes for which quantifying relationships must be developed.

The detachment of soil particles by water is accomplished by two processes. The first involves dislodging soil as a result of the kinetic energy of rainfall. Rainfall is the major detachment process on relatively flat watersheds. The second process involves the separation of particles from the soil mass by shear and lift forces generated by overland flow.

Detachment of soil particles by raindrop impact is calculated using the relationship described by Meyer and Wischmeier (1969):

$$DR = .027C \cdot K \cdot Ai \cdot I^2 \qquad (8)$$

where:
DR = rainfall impact detachment rate, kg/min,
C = cropping and management factor (from Universal Soil Loss Equation), Wischmeier and Smith (1965),
K = soil erosivity factor (from Universal Soil Loss Equation), T/A/EIunit,
Ai = area increment, sq m,
I = rainfall intensity, mm/min.

The detachment of soil particles by overland flow was described by Meyer and Wischmeier (1969) and modified by Foster (1976) as follows:

$$DF = .018 \cdot C \cdot K \cdot Ai \cdot S \cdot Q \qquad (9)$$

where:
DF = overland flow detachment rate, kg/min,
S = slope steepness,
Q = flow rate per unit width, sq m/min.

Once a soil particle has been detached, sufficient energy must be available to transport it or the particle will be deposited. The transport of sediment by overland flow is self-regulating, soil particle detachment by overland flow does not occur unless there is excess energy available in addition to the amount required to transport suspended sediments. However, detachment by rainfall impact often occurs when there is little or no flow available for transport.

After a literature study which included Yalin (1963), Meyer and Wischmeier (1969), Foster and Meyer (1972), and Curtis (1976), as well as an inspection of soils data, a relationship for particle transport in overland flow was chosen as shown in Figure 24.
The two portions of the curve generally represent the laminar and turbulent flow regions. Equations and their region of application are:

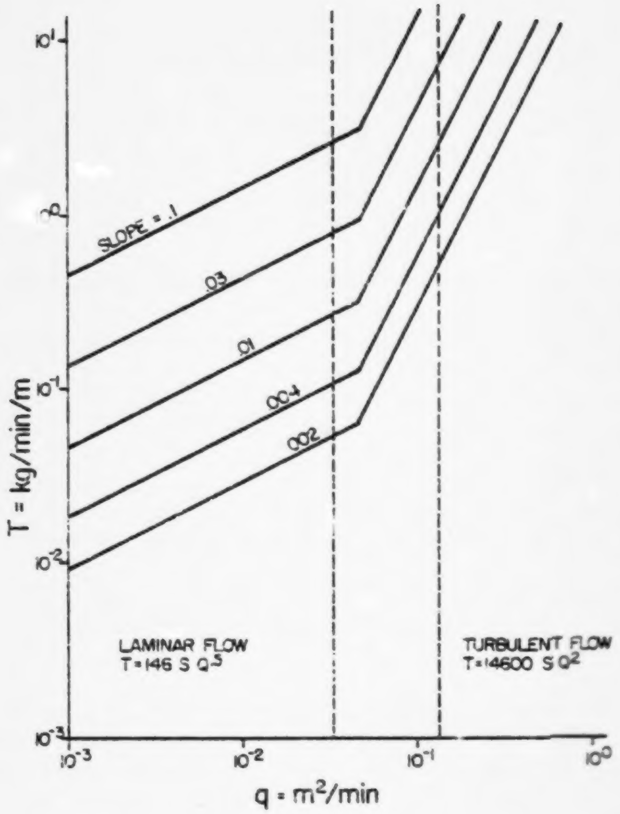


Figure 24. Transport Relationship Used in ANSWERS Model

$$T = 146(S\sqrt{Q}) \qquad \text{if } Q \leq .74 \text{ sq m, and}$$

$$T = 14600(SQ^2) \qquad \text{if } Q > .74 \tag{11}$$

where: T = potential transport rate of sediment, kg/min/m.

Table 86 lists the four particle sizes that were considered as representative in making the transport calculations.

The erosion portion of the ANSWERS model was simplified further by the following assumptions:

1. Subsurface or tile drainage produces no sediment. (Data indicate around two percent of the average annual loading originated from subsurface systems on the Black Creek Watershed).

TABLE 86
Sediment Particle Characteristics

Particle Group	Mean Diameter-mm	Specific Gravity
I	.01	2.65
II	.05	2.65
III	.15	2.00
IV	.30	2.00

2. Sediment detached at one point and deposited at another is reattached to the soil surface.
3. Re-detachment of sediment requires the same amount of energy as required for the original detachment.
4. For channel segments rainfall detachment is assumed to be zero and only deposited sediment is made available for flow detachment, i.e. original channel linings are not erodible.

Although these assumptions were made primarily to reduce the computational cost of using the model, some were also required because little or no data were available in the literature to quantify the particular process.

After consideration of the relative magnitude of the four detachment/transport processes the transport of soil particles by rainfall was assumed negligible.

Combining the above equations and assumptions gives a composite soil movement model wherein soil particles are dislodged from the soil mass by both rainfall and flowing water. Detached solids then become available for transport by overland flow. Within an element the material available for transport is the combination of that detached within the element and that which enters with inflow from adjacent elements.

Once the available detached sediment within an element is known, the transport capacity is computed. If it is insufficient to carry the available material, the excess is deposited in the element. The overall accounting relationship for this process is the differential form of the continuity equation as applied above to water flow. Sediment carried out of an element is apportioned between adjacent elements in direct relation to overland flow.

4.9.1.3 USER CONSIDERATIONS

The selection of a specific model for use as a planning tool is a difficult process complicated by the large number of different models developed in recent years. The most appropriate model to use will depend most of all on the intended application, the type of input data available and the suitability of the output information generated. The accuracy of a model's simulation should also be an important consideration, but unfortunately this is very difficult to judge. Primarily this must be done intuitively by a through study of the relationships incorporated into a model.

ANSWERS represents an attempt to develop a comprehensive model intended to be of use in quantitatively evaluating the importance of non-point source pollution in an ungaged catchment and in determining the relative effectiveness of alternative corrective measures. One of its primary strengths arises from the use of a distributed parameter type of analysis which inherently accounts for the importance of the areal distribution of the many relevant factors. The distributed analysis provides a very complete characterization of hydrologic response and erosion/deposition occurring at all points in the watershed throughout a storm event.

In its present form sediment is the only pollutant for which ANSWERS gives a direct numerical estimate. This is the result of time limitations and the importance of sediment to agricultural non-point pollution. Of course any pollutant which is closely correlated with sediment loss is also easily predicted once erosion losses are known. The modular structure of the model together with the advantages of a distributed modelling concept make the addition of any other pollutants for which component relationships can be developed rather easy.

It was anticipated that the primary use of ANSWERS would be to simulate isolated storm events. This decision was based on the general consensus of erosion research, confirmed by data from Black Creek, that the majority of annual sediment losses result for only a few of the larger storms which occur in a year. In order to use the model for continuous simulation it would be necessary to add component relationships for evapotranspiration and a different integration algorithm for use during periods with no surface runoff.

Selection of an appropriate element size to use with the ANSWERS model is a significant decision from the standpoint of the cost of using the model. Obviously, the larger the element size the lower the cost of input data file preparation (for an area which has not previously been modelled) and the computer costs. Therefore, it is desirable to chose a size which is as large a possible without serious degradation of the accuracy of the subsequent simulation. The most suitable size will depend upon the accuracy requirements of a specific application and on the degree of non-uniformity of topography and soils in the watershed. For the Black Creek Project an element size smaller than considered optimum for ordinary use was deliberately chosen in order to evaluate the influence of element size as a parameter. From that experience it is recommended that an element size in the range of 2-5 ha will be satisfactory for most applications in areas with a variability comparable to Black Creek.

The primary effort required in preparing a data base to use the ANSWERS model on a particular watershed concerns characterizing the topography and soil type of each element. Where computer compatible data files with such information are not available, U.S. Geological Survey Topographic Maps and County Soil Survey Maps must be used. While these sources of information are quite adequate, the effort required to digitize the information is not trivial.

A frequent complaint voiced by potential users of comprehensive watershed models is the large volume of data required concerning watershed characteristics. This comment is often directed at distributed parameter models because a large data base is usually required. However, one of the fundamental strengths of comprehensive models is their potential ability to characterize the many processes for which input coefficients must be specified. When data are not available to quantify some coefficients, assumed values can be supplied. While one is never comfortable in such a situation, it is easy to use a comprehensive model to evaluate the sensitivity of the prediction to changes in assumed values.

In contrast, "simpler" models that require less input have incorporated at creation time implicit assumptions concerning all variables for which explicit numerical values are not demanded from the user. Because these assumptions are implicit the user has neither control over them nor any means of evaluating their importance. Thus, while it is desirable to have available hard data to quantify all parameters of a comprehensive model, it is better to assume values for a model than to submit to the rigidity of implicit assumptions inherent with simpler models.

It is anticipated that future versions of ANSWERS will contain default values for all parameters so that completely inexperienced personnel would not be required to make assumptions about initial parameter values in the absence of hard data.

4.9.1.4 RESULTS

Verification of the accuracy with which a model such as ANSWERS can simulate the behavior of natural watersheds is, in a strict sense, impossible. This situation results from the number of degrees of freedom, i.e. coefficient values, of the model. It is true that optimization techniques could, given enough computer time, yield a set of coefficients which would give an "accurate" simulation of almost any gaged event(s). However, since it is not feasible to obtain field data to authenticate the correctness of each of these optimized coefficients, such an effort would not prove the model is accurate.

Fortunately, from the standpoint of application of a model for planning analysis or design, one needs to simulate hypothetical future events rather than accurately reproduce historical records. For such uses massive amounts of data concerning antecedent conditions (with their associated coefficient values) are irrelevant. Coefficient values for such hypothetical situations must be determined from probabilistic relationships rather than measured conditions. Therefore, massive data collection efforts are not required for operational use of the model.

Despite the impossibility of absolute model verification, a real need exists to provide some measure of the accuracy of a model's simulation during its developmental period. Ultimately this comes down to comparing its output with gaged data from specific events on natural watersheds. Several complex storm events which occurred during 1975 and 1976 were simulated for two gaged subcatchments of the Black Creek. These subcatchments were 714 and 942 ha (1765 and 2328 A) in size. Beasley (1977) gives a detailed discussion of these results. While they varied somewhat from one storm to another and on the basis of evaluation criteria, the results were generally within 30 percent of gaged values for all criteria.

From a pollution control planning standpoint the most relevant question is "What needs to be done to achieve stated water quality standards for a particular area?" The first step necessary to rationally respond to such a question is a quantitative assessment of current conditions. The strength of using a distributed model for this purpose is best illustrated with an example.

Figures 25 and 26 illustrate some of the more applicable outputs available from an ANSWERS simulation. They were produced by simulating the behavior of a 714 ha subcatchment of the Black Creek Watershed using 1 ha elements together with cropping, management and rainfall data for the specified date.

Figure 25 gives output typical of a lumped model, runoff and sediment concentration hydrographs at the watershed outlet. The simulated volume was within 9 percent of the gaged amount (19 mm) and the total sediment yield within 13 percent of the observed amount (325000 kg). These quantities were produced from a storm with 64 mm of rainfall.

Any benefits of using a distributed parameter model instead of a lumped one are not obvious from Figure 25. While it was claimed above that the distributed approach makes possible a more accurate simulation, a single example of close agreement between gaged and simulated results is totally inadequate to judge to validity of such a claim. Furthermore, even an extensive set of comparative simulations using ANSWERS and the best of available lumped models could establish only the relative merit between the two specific models. This would not offer conclusive evidence concerning which of the two fundamental philosophies was superior.

Figure 26 clearly illustrates one major advantage of a distributed model, more comprehensive output information. The "contour" lines on the map result from connecting points within the watershed which experienced equal soil detachment during the storm. Thus areas with closely spaced lines correspond to regions of intense erosion. Such maps readily identify those regions where control measures should first be considered.

Figure 26 indicates the bulk of the erosion occurred in the upland portion of the watershed (the most steeply sloping region) with two small areas experiencing a loss of more than 14000 kg/ha. The general location of severe erosion could certainly have been predicted by any person familiar with the area and reasonably knowledgeable of erosion processes. The reason for modelling the area's behavior is not to identify the location of problem areas, but to obtain a quantitative estimate of both the amount of soil eroded and of its impact on water quality.

Maps similar to Figure 26 can be produced upon request for other factors in addition to eroded soil. For example, a deposition map or concentration hydrographs at any point within the watershed are also available to a planner or designer.

It is worth emphasizing that ANSWERS' prediction of both field erosion and sediment concentrations in flowing water is based upon detachment/transport relationships used in conjunction with topographic data about the watershed. That approach eliminates the need to use a

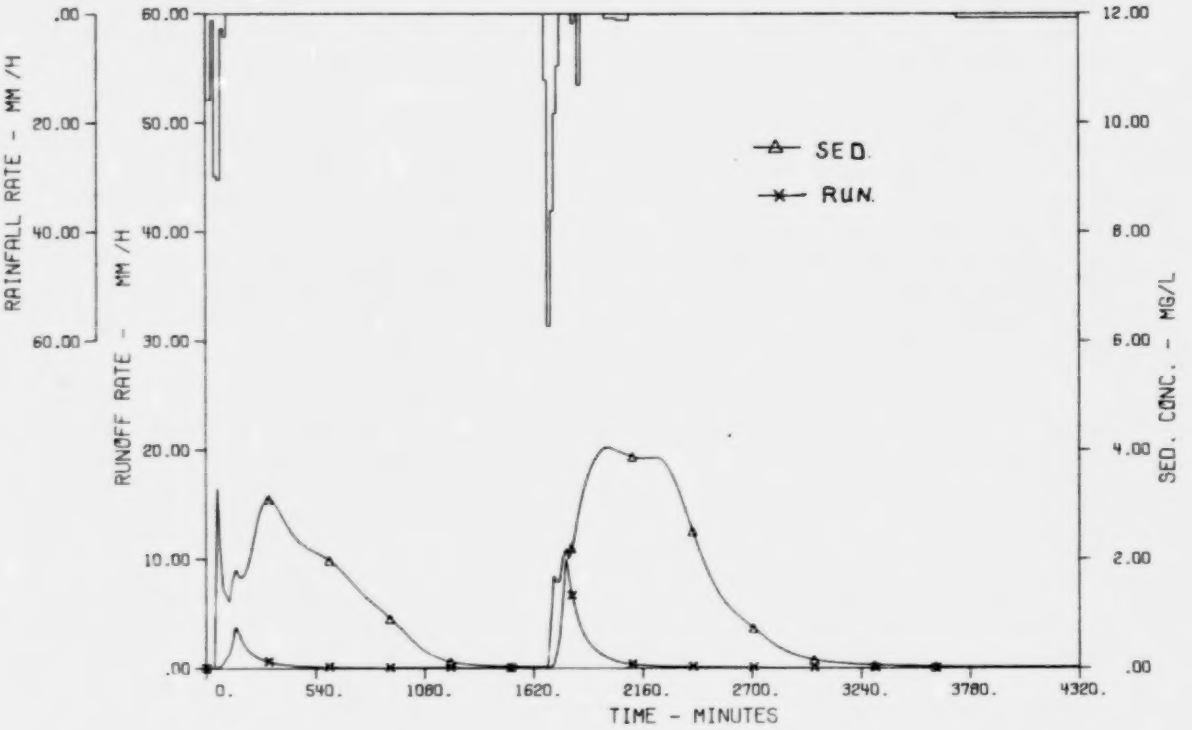
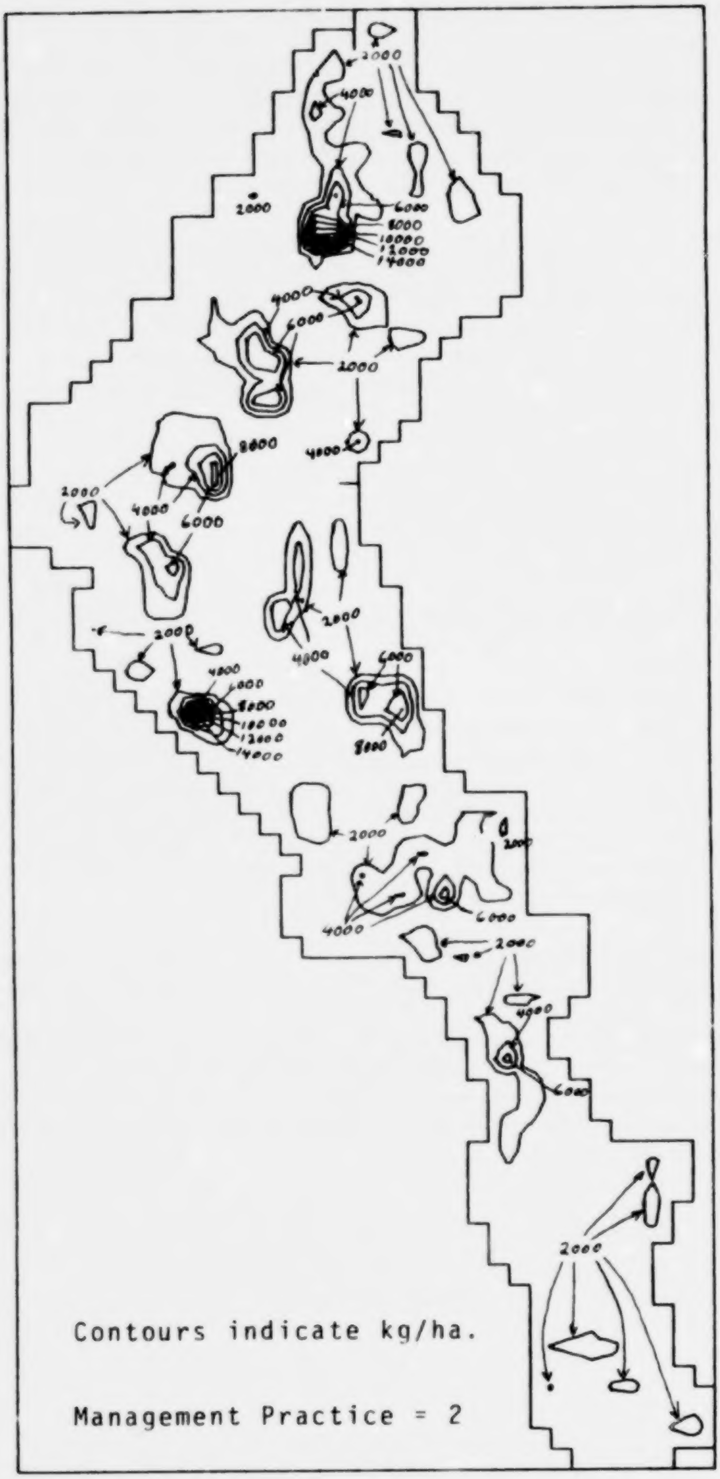


Figure 25. Runoff Rate vs Time in Minutes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Contours indicate kg/ha.

Management Practice = 2

Figure 26. Sediment Loss

"delivery ratio" concept which is difficult (some would say impossible) to accurately quantify for the infinite variety of situations which occur in natural catchments.

The second step in developing a program to meet water quality standards for an area involves formulating and evaluating the effects of alternative strategies. The detailed output of a distributed model is ideally suited to this iterative step of planning.

Figure 27 shows what ANSWERS predicts would be the effect of a hypothetical change in tillage practice for the entire catchment. The actual tillage practice used on almost all grain fields in the watershed is fall moldboard plowing. Figure 26 was generated with that tillage practice specified. Figure 27 was generated under the assumption that moldboard plowing would be replaced by fall chisel plowing for all cropland in the catchment.

In contrast to the moldboard plow, the chisel plow leaves more crop residue on the surface and a rougher micro-relief which tends to enhance infiltration. Comparison of the two simulation results shows the impact of such a management change on the resulting erosion pattern. Integration of the sediment concentration hydrograph at the watershed's outlet indicates only 1/3 of the sediment yield simulated for current management practices.

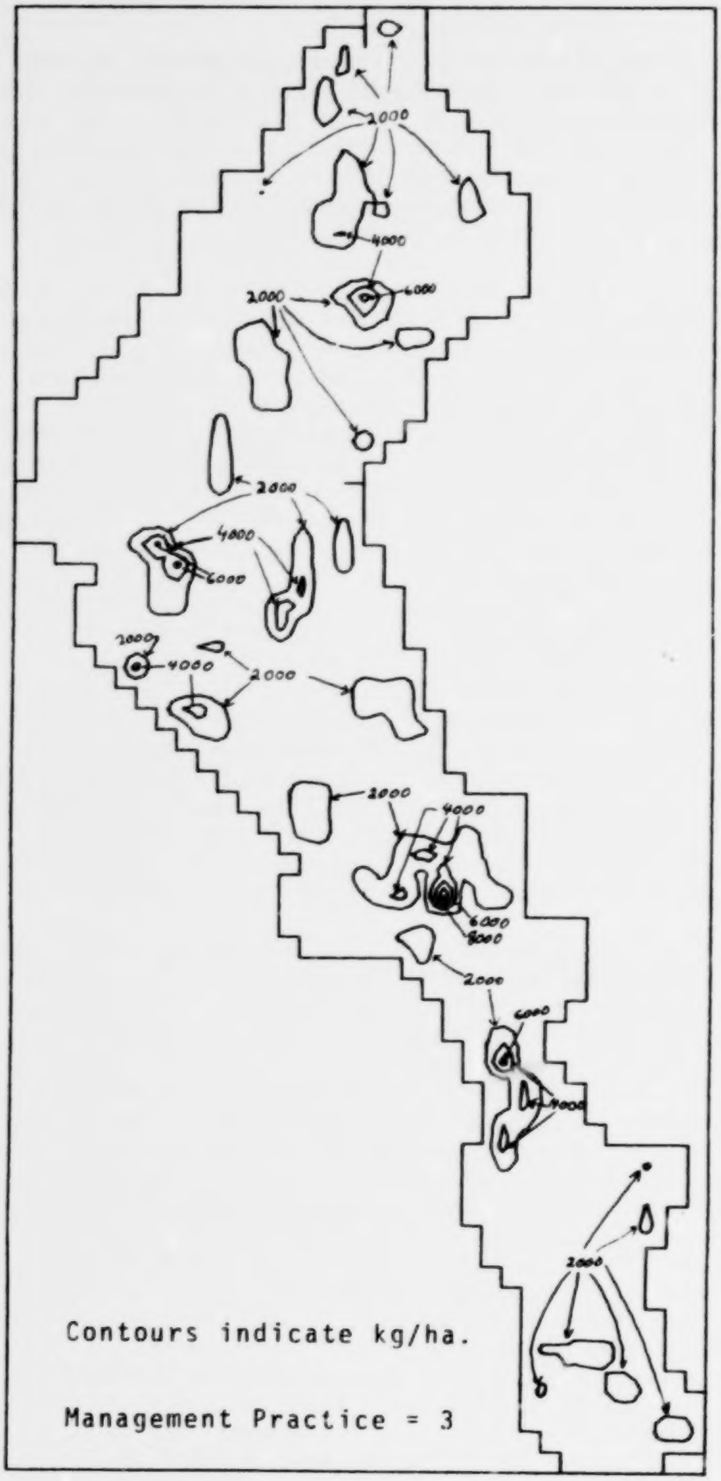
The purpose of this example is not to praise the benefits of a specific tillage practice. In fact, the cost effectiveness, political acceptability and long-term consequences (such as unforseen weed or pest problems) of making significant management changes on a widespread scale are often questionable. Such a course of action for this catchment would never be recommended if the information from the simulation shown in Figure 26 is fully utilized. That figure clearly shows the major erosion occurs from few a localized regions. It is on these specific areas that control measures should first be evaluated.

Figure 28 shows an ANSWERS simulation of the effect of changing to chisel plowing in only two of the highest erosion regions, those enclosed by broken lines.
The total area of these two regions is only 32 ha of the watershed area of 714 ha. Integration of the outflow hydrographs indicates that changing tillage on only these two small areas would achieve 40 percent of the sediment yield reduction that could be achieved by changing the management of the entire watershed.

It is the ability to be very site-specific concerning implementation plans and to quantitatively demonstrate the effects of hypothetical control measures on both upland regions and water quality conditions throughout the watershed that makes a distributed parameter model such an effective planning tool.

4.9.1.5 CONCLUSIONS

A comprehensive, non-point source watershed simulator, named ANSWERS, has been developed. It was designed around a distributed parameter concept with the intention of giving an accurate, comprehensive description of a watershed's behavior during and immediately following storm events. The purpose of this effort was to develop a model for use during the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Contours indicate kg/ha.
Management Practice = 3

Figure 27. Upper Black Creek Watershed, Local Net Sediment Loss

The primary strengths of the distributed parameter approach are its inherent accuracy, especially for ungaged situations such as evaluating the influence of hypothetical changes to a watershed, and its detailed description of the behavior of all interior points within a catchment's boundaries. The primary disadvantage of the approach is that the cost, for both data preparation and computer time, to use it increases somewhat proportionally to the area being simulated.

While it is not possible to give rigid limits as to the maximum area that can be simulated without resorting to subdivision into smaller units, current computer technology would suggest an upper limit in the range of 50 to 200 sq km. This is not considered to be a serious handicap to the utility of the ANSWERS model to 208 implementation planning because its intended use is on relatively small areas where detailed information is needed. Other coarser procedures can be used on a "first pass" basis to identify subregions of a large basin which have significant non-point pollution problems and therefore warrant the use of a distributed model prior to spending public funds to alleviate the problem. Solomon and Gupta (1977), using a model structure identical to that employed in the ANSWERS model, but with entirely different component relationships have developed a distributed model intended for use on a river basin scale.

Extrapolation of unit cost data for various non-point pollution control measures and the watershed simulation example discussed above lead to the same conclusion. In order to be feasible, any non-point source program must be highly site specific. Attempts to treat large areas with a uniform set of practices or regulations will so dilute available funds that the program will have little chance of being effective or publicly accepted. ANSWERS offers a unique planning tool to help formulate site specific non-point source programs for agricultural areas.

Annual loading data presented in earlier Black Creek reports and elsewhere in this volume have shown values which, when presented on a per hectare basis, are relatively low (on the order of 1000 kg/ha). This value has been, by some individuals, contrasted with values for "tolerable soil loss" used in conjunction with the Universal Soil Loss Equation to draw incorrect implications concerning the potential effectiveness of BMP's to improve water quality. Such comparisons are incorrect for several reasons. First, it is almost always meaningless to use values (either for soil losses or unit costs) based on averages per hectar over an entire watershed to make extrapolations to another watershed, especially of a much larger size. Secondly, the USLE tolerable soil loss values are for gross soil erosion on upland areas, not net transport at the outlet of a watershed. Because of this there is no reason to believe that those loss values, developed with the sole criteria of preserving long-term productivity, are directly applicable from the standpoint of water quality. Finally, the ANSWERS example presented above clearly demonstrates the falsity of drawing a conclusion to the effect that "because loadings (on a per hectare basis over the watershed) are significantly below some `acceptable level' it is either unnecessary or maybe futile to consider a BMP." The model indicated that for a specific storm with an average sediment yield of 460 kg/ha more than 25 percent of the yield could have been prevented by a different tillage practice on only 32 ha of the 714 ha catchment.

The ANSWERS model is operational and available to anyone interested in using it. Because of the limited number of geographic regions on which it

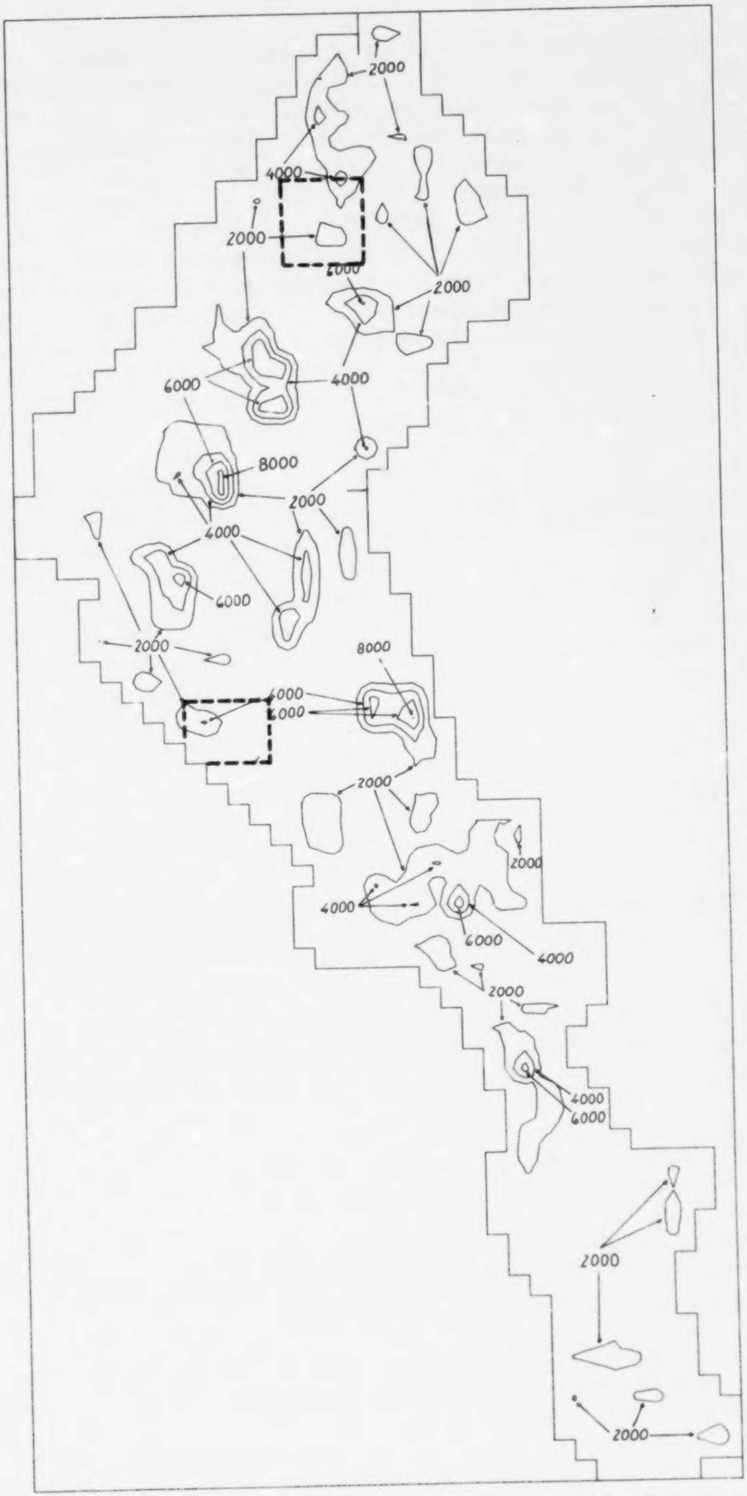
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Figure 28. Effect of BMP's on Only Critical Areas

has been verified it must still be considered to be in a stage of development rather than a fully operation model ready for widespread use.

The primary reason for this status is the lack of parameter values tested for numerous regions. However, it should be emphasized that parameter values required by the model have been designed to be ones with a known physical analogy rather that "black box" coefficients requiring extensive calibration in order to establish values. This means it is generally possible to obtain parameter values which are regionally dependent from available publications, e.g. Soil Survey Reports and publications containing USLE soil erodibility and cropping factor coefficients. Because of the availability of such data and because of the great flexibility of the model, it is considered applicable to a broad range of conditions and areas. Finally, if hard data are not available for a few parameters it is possible to estimate their values relative to published values for similar conditions and then use the model to evaluate the sensitivity of the watershed to a plausible range for those values.

Two kinds of materials are available to assist users of the ANSWERS model: a user's manual for persons interested it the direct utilization of the current version of the model in a planning/design application and a manual describing concepts and the inner structure of the model for persons interested in changing component relations used or in adding relationships to model additional processes. These materials are available from the Department of Agricultural Engineering, Purdue University, W. Lafayette, IN 47907.

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4.9.2 Tile Drainage Simulation Model

A computerized simulation model has been developed to provide a predictive tool for determination of sediment losses from tile effluent. The model provides a flow hydrograph with associated sediment loading as a function of the input variables (rainfall and initial soil moisture content). The model will have the capability of being modified to represent different tile system designs and soil types.

The need for concern of tile drainage influence on water quality is shown by the significant contribution it has to stream flow. Approximately 50 percent of the Black Creek Watershed is drained by subsurface tile systems. A tile system can contribute anywhere from 10 to 100 percent (typically 30 percent) of the total runoff of a drained area. This indicates that approximately 15 percent of the runoff per year from Black Creek is tile effluent. During non-storm periods tile effluent is the major source for stream flow in agricultural areas. The influence of tile flow on stream flow may vary greatly depending on the annual rainfall distribution.

An estimate of the sediment, phosphorus and nitrogen going into the Maumee River from Black Creek tile effluent is approximately 19, .036 and 2.7 kilograms per hectare per year, respectively. This is based on the previous flow assumption and tile effluent data collected by grab sampling on 266 tile outlets in the Black Creek Watershed. The loading rates of localized areas can be much larger as shown by G. O. Schwab (1973). He measured annual sediment losses from tiles as high as 5400 kg/hect/year. His results indicate that in some critical areas the tile effluent may be the dominant effect on stream water quality.

4.9.2.1 BACKGROUND

Glacial tilled soils of the Midwest seem to be susceptible to erosion losses through tiles. The soils drained by tiles generally have high silt and clay contents. These fine particles are able to be detached and transported within the soil profile by forces exerted on them by flowing water. The actual detachment and transport mechanisms within a soil profile are not well understood, but many studies have been done in closely related areas such as piping effects and force balance relationships within soils.

A model by D. Zaslavsky (1965) describes the force balance of particles in cohesive soils. This model also shows the implied interrelationship of flow gradients to fine particle movement. Particularly it indicates that for a given particle size a threshold flow level must be reached before particle movement will occur. The effect of the flow channel size on the threshold flow is also provided. Zaslavsky's model uses these relationships to obtain an expression which relates the critical (threshold) flow for particle movement to a given particle size assuming a mean pore channel size. To extend the use of Zaslavsky's model for an erosion yield model it becomes necessary to attach a probabilistic detachment model to the basic force balance relationships. Thus a probability is associated with the critical flow and has a functional relationship to flow above the critical flow. So for a given particle size and flow rate it is possible to show a distribution of detachment potential for a particle size distribution. The probabilistic approach used by H. A. Einstein (1950) provided excellent results for particle detachment and transport in open channels.

The particle detachment model described above requires knowledge of the water flux distribution within the soil profile. Several tile flow models (4) are available, but none are uniquely suited for a tile erosion model. Therefore a two-dimensional porous medium flow model has been developed to provide the necessary water flux distribution within the soil profile. The flow in the unsaturated profile region is determined by Darcy's Law which is the tension-conductivity method. The flow at the tile will be tentatively determined by Toksoz and Kirkham's formula (1961) using the watertable height above the tile. This tile flow formula was developed for a constant infiltration rate passing through an unsaturated layer into a saturated layer. This indicates continuity at the watertable which is required to effectively model across this transition layer. Continuity is expressed as:

$$\text{Change in water storage} = \text{Inflow} - \text{Outflow}$$

Using the assumption that a known geometric flow pattern exists near the tile, the magnitude of water movement near the tile can be generated as a function of R and 0 (radian distance and angular direction from tile, respectively). Flow nets are available for several different soil profiles above tiles (1957). The water flux is then used to determine the relative volume of soil which is experiencing a certain erosion potential. These volumes are then summed for all erosion potentials for given particle sizes to determine total erosion potential. As indicated, the sediment loss is determined as a distribution shape and therefore absolute magnitudes are not directly provided by this approach. Field data is needed to quantify the sediment loss distribution.

4.9.2.2 MODEL FOR PARTICLE DETACHMENT

The forces acting on a soil particle can be summarized as:

Fg -- gravitation force
Fc -- cohesive force (attraction between particles)
Fh -- hydraulic forces (caused by water movement)
Fp -- point forces (caused by physical contact with other particles)

To get particle movement, the hydraulic forces Fh must exceed the sum of all the other forces, that is,

$$F_h > F_g + F_p + F_e \qquad (12)$$

4.9.2.2.1 Gravitation Force

The effective gravitation force is the submerged weight of a particle.

$$F_g = V(G - 1)\gamma_w \qquad (13)$$

The variables in the above expression are described as follows: V is the volume of the particle, G is its specific gravity and γ_w is the unit weight of water. It is of course possible for the gravitation force to be in any direction with respect to the detachment force F_HHowever, direction will be taken care of because all forces are represented as vector quantities.

4.9.2.2.2 Cohesive Force

Cohesive forces are the result of electrostatic-interactions of very small particles. These forces are not well understood, but they can be correlated to the overall tensile strength (ease of pulling apart) of a soil. Cohesion is normally determined by the amount of stress to cause a failure in shear for a zero load on samples. The overall cohesive force per unit area, which can be measured as above, can be represented as the sum of all the individual cohesive forces for each particle in the layer of shear.

$$\frac{\text{Cohesive Force}}{A} = \sigma = a_1A_1\sigma_1 + a_2A_2\sigma_2 + \ldots\ldots + a_nA_n\sigma_n \qquad (14)$$

or

$$A\sigma = A\sigma\int f(D)\,dD \qquad (15)$$

therefore,

$$F_c(D_i) = \frac{A}{f_i n} \int_{(D_i - \Delta D)}^{(D_i + \Delta D)} f(D)\,dD \qquad (16)$$

The variables in the above expressions are described as follows: A is area of test sample, α is failure stress of test sample,a_i is a geometric factor for the i-th particles shape, A_i is the i-th particle area which is influenced by the shear-stress, $\alpha_i$is the stress of the i-th particles, n is the number of particles in the test layer, D is a particles size, f_i is the fraction of particles in the i-th particle interval which has a $2\Delta D$width. The density function f(D) should be proportional to the square inverse of the particle size and directly proportional to the particle distribution.

4.9.2.2.3 Hydraulic Forces

A particle experiences drag and lift forces when flowing water passes over it. The sum of these forces is equal to the overall hydraulic force, that is,

$$F_h = F_{lift} + F_{drag} \qquad (17)$$

Drag forces are given by Stokes Law:

$$F_d = \frac{24Ap}{R_e} \frac{\rho Vs^2}{2} \qquad (18)$$

Parameters are described as follows: Ap is the effective area factor (accounts for particle size exposed to the stream flow V_s,$R_e$is Reynold's Number, and ρ is the density of water.

The lift force on a particle is developed when the water flows faster over one side of the particle than the other. The lift force for an attached particle can be expressed as a function of its exposed surface and the velocity of water across its surface.

$$F_L = C_L K_1 D^2 \rho \frac{V_b}{2} \qquad (19)$$

Parameters not previously described are as follows: C_l lift coefficient and $F_1$is exposed surface factor.

4.9.2.2.4 Ratio of Non-Point Forces

For particle detachment the hydraulic force must exceed the sum of the cohesive and gravitational forces or expressed as a ratio.

$$\frac{F_g + F_c}{F_h} = R < 1 \qquad (20)$$

If the ratio R is less than unity then the potential for erosion exists. However, the above expression assumes that all particles of the same size experience the same cohesive force. This was not the case, so a normal distribution was assumed such that a probability exists for particle detachment for R's slightly greater than one. This serves to smooth out the computer summation of the erosion potentials.

4.9.2.2.5 Point Forces

The point forces are impossible to describe for any one particle. The magnitude of these forces can be very large, but intuitively one can reason that only the particles near a free surface will have any possibility of small or zero point forces. Within a soil profile only the smaller particles (clay and silt) will see free surfaces in the pore cavities and channels. A probability p for detachment must be associated with each particle size D to account for the point forces. Now the probability of detachment is the probability that the point force F_i is less than all the other forces, that is,

$$\text{Prob}\ [F_p < F_h(1 - R)] = p(D,R) \tag{21}$$

This functional relationship of p will vary by soil type and depth in profile.

4.9.2.3 DISCUSSION

Several of the relationships presented are not easily determined experimentally. Therefore, some assumed relationships will be used initially until reliable laboratory data is available. The accuracy of the model to predict actual erosion losses will serve to validate or disprove assumed relationships. It should be noted that all forces are vector quantities and therefore, the numeric analysis of the erosion model will be more complex than indicated above.

The time dependence of the detachment mechanism is represented by the probabilistic relationships of the point hydraulic forces. In order to change the erosion potential of a particle either the flow must change or another particle near it must move. So over time the loss of surface particles increases the probability of detachment of particles beneath the surface layer. Armoring will occur over time, but for this model it is assumed that natural soil weathering will periodically recharge the smaller particles in the pore cavities and channels.

To use the particle detachment model, it is convenient to combine the probabilistic and force balance relationships into one erosion potential expression for a tile system. The detachment model provides a fraction of particles detached per unit area per unit time for the particle distribution interval $D \pm \Delta D$ at a given water flux. Define erosion potential as the ratio of erosion rate at tile flow TQ to the erosion rate at maximum tile flow. It is now possible to compute the erosion potential at a TQ by making the assumptions of geometric flow net and the same soil texture throughout the profile. The computation requires an integration over the entire soil profile for each particle size interval used and then the addition of the results. For Zaslavsky's relationship and a radial flow assumotion the erosion potential is given as:

$$EP = \frac{\sum f_i \left(\frac{TQ}{Q_{cr_i}} - 1 \right)}{\sum f_i \left(\frac{TQ_{max}}{Q_{cr_i}} - 1 \right)} \tag{22}$$

The parameter Q_{cr_i} is the critical flow for a given particle size .

4.9.2.4 COMPUTER MODEL

The tile model is programmed in the GASP IV Simulation Language. GASP IV was selected because of its advanced time stepping and differential equation solving techniques. The computer model breaks the soil profile above the tile into N layers (see Figure 29).

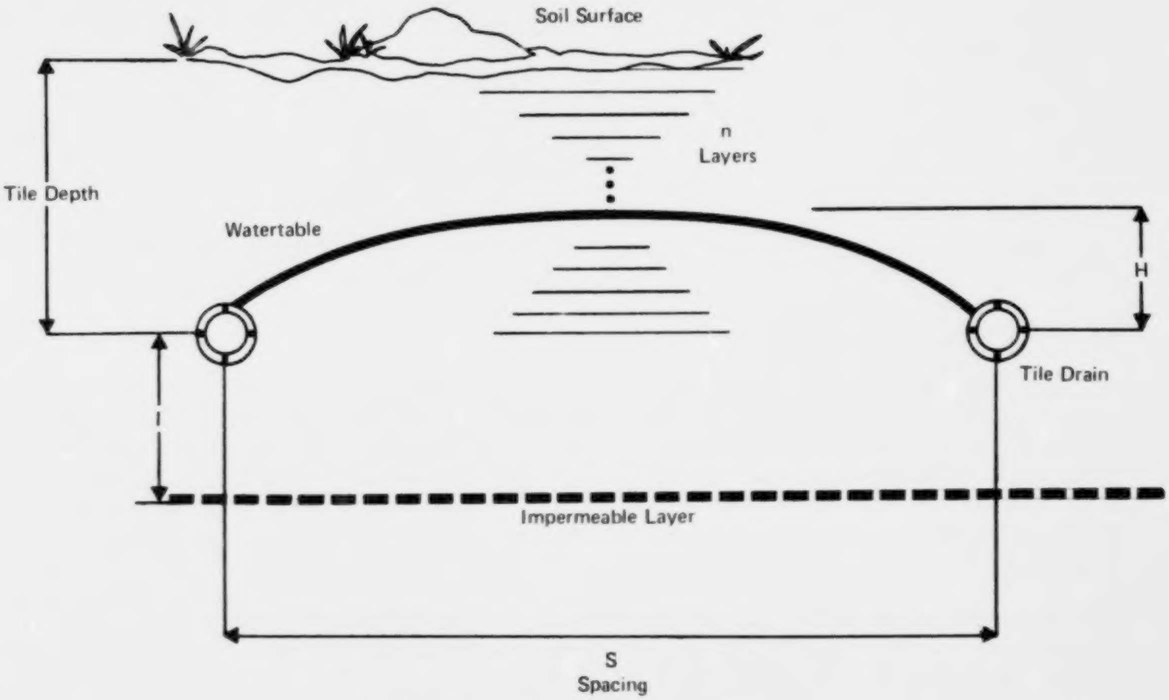

Figure 29. Tile system Layout

Hydraulic conductivity for each layer can be provided separately. This gives tremendous latitude in the types of soil profiles which can be analyzed. Flow between each layer is determined for each time step by use of Darcy's Law.

$$q = k \left[\frac{\partial (T + Z)}{\partial Z} \right] \Delta t \tag{23}$$

Continuity at the watertable is determined by comparison of the flow into the layer in which the watertable is located and the flow out the tile as determined by Toksoz and Kirkham's method.

$$\text{TQ (tile flow)} = \frac{KH}{SF+H} \tag{24}$$

Parameters described above are as follows: q is vertical water flux, K is hydraulic conductivity, T is tension head, Z is elevation head, t is time, H is height of watertable above tile center, S is tile spacing, and F is geometry coefficient for the tile system layout. Initial attempts will use Zaslavsky's piping relation, and associated erosion potential. The probabilistic model will be added when fully developed.

The computer model solves the above relationships for any rainfall distribution provided. The output of the model is a plot and table of tile outflow and sediment loading rate as a function of time. Also, at any time during the simulation a moisture plot can be obtained for the soil profile above tile.

4.9.2.4.1 Discussion

A similar problem exists for the hydraulic model as in the detachment model, that is, some of the parameters are not readily available and when available are in a graphic form. Graphs are empirically hard to represent in a computer program if they do not have a functional relationship (equation) which will represent them. This is the problem with many of the required parameters for the tile erosion model. The relationship of tension and hydraulic conductivity exhibit hysteresis which further complicates exact determination. Because of these determination problems linear assumptions are made for some of the relationships. It will be done so that the parameter's representation will be within obtainable experimental error. Linearization also greatly increases the efficiency of the computer program.

4.9.2.5 CALIBRATION USING TILE SAMPLER DATA

Field data is essential to calibrate and verify the computer model. As indicated the sediment loss potential as determined by the model does not provide absolute magnitudes of the sediment loss directly. To calibrate this potential distribution at least one water quality sample is needed during a significant flow period. This in itself does not assure that the computed shape of the potential distribution is correct. Therefore, it is necessary to have water quality data for as many flow conditions as possible in order to compare the distribution shapes of both the actual and simulated sediment loss curves. To obtain this data base an automatic pumping tile sampler was installed on a tile draining forty-three acres of a typical soil type (Hoytville) of the Black Creek Watershed.

4.9.2.6 AUTOMATIC TILE SAMPLER

An automatic tile sampler has been operational since March, 1976. The peak flow periods for tiles are during the winter and spring months. Therefore, the equivalent of two years of data for calibration and verification of the tile model should be available by late spring of 1977. This pump sampler data has also been analyzed to provide loading rates directly for the determination the tile effluents effect on water quality. The fertilizer nutrients have also been looked at closely to define their loss rate through the tile system.

The operation of the tile sampling station is unique in that discrete water quality samples are collected proportionally to the tile outflow, which is continuously monitored and recorded. The time at which a sample is collected is also recorded on the flow hydrograph chart. The sampler has the capability of collecting 72-500 ml water samples. The sampler rates are approximately 1 sample per 30 minutes at maximum flow decreasing to 1 sample per 12 hours at low flow. Another feature of the tile sampling station is prevention of the tile outlet from becoming inundated. This is necessary to provide reliable data during storm events in which the ditch water level is above the tile outlet. Two 200 GPM pumps used in conjunction with a sump maintain a free water fall over the flow calibrated weir. Pump "on" times are also recorded to provide a check for the water volume passing through the station. See Figure 30 for more detail of the tile monitoring station.

4.9.2.7 SUMMARY

The hydrologic model is working for the assumptions previously mentioned and for a modified non-linear moisture-tension relationship which was determined by laboratory experiments. The model's output is in close agreement with field data. The hydraulic conductivity-moisture relationship is not yet fully developed, therefore further refinement of the model is expected. The sediment detachment model will be attached to the hydrologic model when the hydrologic model is fully calibrated.

The sampler station has functioned well for the past two years. The collected samples have been analyzed for sediment and nutrient concentrations. Results of this analysis are given in Section 0.0.

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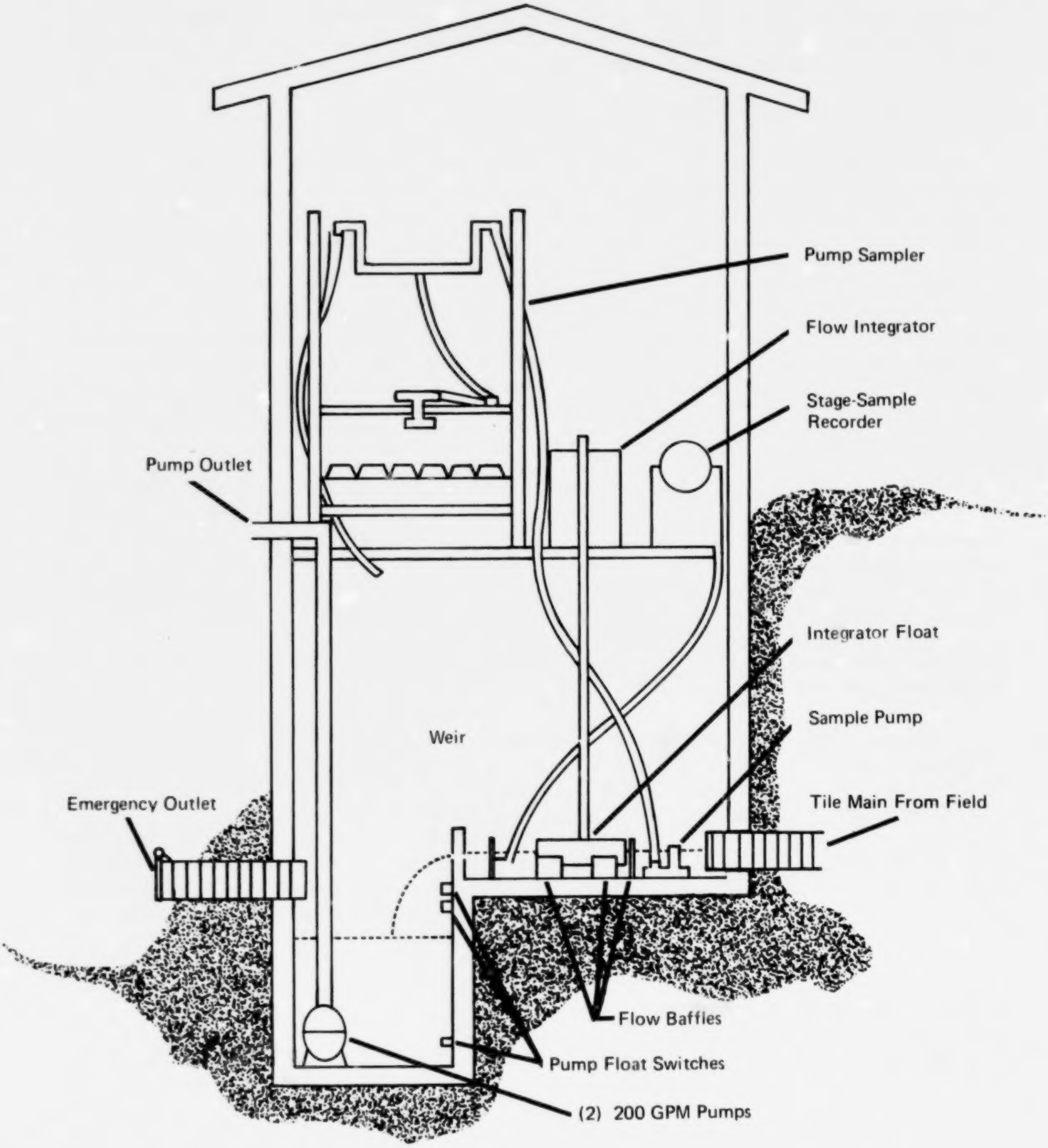
Pump Sampler
Flow Integrator
Stage-Sample Recorder
Pump Outlet
Integrator Float
Sample Pump
Weir
Emergency Outlet
Tile Main From Field
Flow Baffles
Pump Float Switches
(2) 200 GPM Pumps

Figure 30. Automatic Tile Sampling Station

4.10 STUDIES OF NUTRIENT AVAILABILITY

Laboratory incubation experiments were conducted to evaluate the transformations of nitrogen and phosphorus in water systems. These transformations are important in determining the fate of N and P entering water resources from agricultural land.

4.10.1 Effect of Incubation Temperature

The temperate zone of the U.S. is subject to wide variations in air temperature throughout the year and thus, the temperature regime in surface waters will vary diurnally and seasonally. The effects of incubation temperature on the soluble phosphorus and inorganic nitrogen composition of creek water are given in Table 87. The concentration of soluble inorganic phosphorus increased significantly with time at all incubation temperatures; however, the increases were greater at higher temperatures. The increase in inorganic phosphorus was approximately one-third greater for samples incubated at 33 degrees C as compared to those incubated at 5 degrees C. The soluble organic phosphorus concentration in samples decreased with time, but the rate of decrease was slower at the lowest incubation temperature.

The concentration of total soluble phosphorus generally increased with time of incubation. This finding suggests that the increase in soluble inorganic phosphorus in samples is not entirely the result of mineralization of soluble organic phosphorus, but may in part result from desorption of inorganic phosphorus from the sediment or mineralization of organic phosphorus in the sediment. During the 12 weeks of incubation 1.8, 2.1, 3.75, and 8.25 μg of phosphorus per sample were released from the sediment to the solution phase of samples incubated at 5, 15, 23, and 33 degrees C respectively.

In all samples except those incubated at 33 degrees C, the ammonium-nitrogen content increased during the first week, probably as a result of mineralization of organic nitrogen. Nitrification was rapid in samples incubated at all temperatures as evidenced by the increase in nitrate content with time. The nitrate concentration in incubated samples increased steadily with time and reached approximately the same level in all treatments after 12 weeks of incubation. After 12 weeks of incubation 188, 224, 218, 231 μg of nitrogen per sample were released from the sediment to the solution phase in samples incubated at 5, 13,23, and 33 degrees C, respectively. The increase in soluble inorganic nitrogen is likely the result of mineralization of organic nitrogen present in the sediment phase of creek water.

As stated previously, temperature has a definite effect on the rate with which insoluble nutrients become available and on the amount of nutrients that are converted to water soluble forms. The increasing amounts of nitrogen and phosphorus converted to water soluble forms were directly proportional to the incubation temperature. This is a significant finding since aquatic plants exhibit accelerated growth rates during periods of elevated water temperature, provided the temperature is within the optimum range for growth. If water temperatures increase in a lake or pond in which algal growth is a problem, the data obtained from incubation experiments indicate that increased amounts of nitrogen and phosphorus will become available to aquatic plants. In lakes where the temperature does

TABLE 87
Effect of Temperature on the Concentration of Solution N and P

Treatment Degrees C	Incubation time (weeks)	Concentration of soluble				Change in concentration during incubation	
		Inorg-P	Org. P	Amm.-N	Nit.-N	Sol-P	Sol.inorg-N
		mg/l					
5	0	.189	.104	0.54	2.88	-	-
	1	.161	.132	0.97	2.92	.000	.47
	3	.182	.123	1.20	3.19	.012	.97
	6	.280	.093	0.76	3.86	.080	1.20
	12	.286	.019	0.10	4.57	.012	1.25
13	0	.189	.104	0.54	2.88	-	-
	1	.210	.076	1.16	2.92	-.007	.66
	3	.261	.017	0.24	4.28	-.015	1.10
	6	.288	.043	0.10	4.59	.038	1.27
	12	.295	.012	0.07	4.84	.014	1.49
23	0	.189	.104	.054	2.88	-	-
	1	.220	.090	1.15	2.97	.017	0.70
	3	.258	.024	0.21	4.36	-.003	1.15
	6	.309	.018	0.22	4.84	.034	1.64
	12	.314	.004	0.10	4.77	.125	1.45
33	0	.189	.104	0.54	2.88	-	-
	1	.279	.080	0.19	3.82	-.066	0.59
	3	.280	.018	0.16	4.10	.005	0.84
	6	.315	.024	0.22	4.93	.046	1.73
	12	.340	.008	0.07	4.89	.055	1.54

not exceed 5 degrees C, the nutrient status would be much lower and thus, reduce the potential for the growth of aquatic plants.

4.10.2 Effect of Aeration Status and Shaking

Sediments are subjected to various levels of aeration during transportation and deposition in natural waters. Aeration is known to have a great effect upon the soluble nitrogen and phosphorus in water-sediment systems. It is essential to determine the role of sediments in supplying soluble nutrients in natural water systems.

The effects of aeration status and shaking on the soluble nitrogen and phosphorus components of creek water incubated for 12 weeks is given in Table 88.

It was anticipated that shaking would increase the degree of aeration in samples; however, there was little difference in dissolved oxygen content of static or shaken samples. The dissolved oxygen measurements taken after incubation of helium purged samples show that that anaerobic conditions were not maintained throughout the incubation period; however, the dissolved oxygen content was much lower than in those samples which were

TABLE 88
Effect of Aeration and Shaking on the Concentration of Soluble N and P

Treatment	Incubation time (weeks)	Dissolved O2 content	Concentration of soluble				Change in concentration during incubation	
			Inorg P	Org. P	NH_4^+-N	NO_3^--N	Sol-P	Sol inorg-2
		mg/l					mg/l	
Aerobic static	0	-	0.189	0.104	0.54	2.88	-	-
	1	8.60	0.220	0.090	1.15	2.97	0.017	0.70
	3	8.85	0.258	0.024	0.21	4.36	0.003	1.15
	6	9.40	0.309	0.018	0.22	4.84	0.034	1.64
	12	9.55	0.314	0.004	0.10	4.77	0.025	1.45
Aerobic shake	0	-	0.189	0.104	0.54	2.88	-	-
	1	8.70	0.275	0.110	0.07	4.12	0.092	0.77
	3	8.75	0.342	0.000	0.19	4.79	0.049	1.56
	6	-	-	-	-	-	-	-
	12	9.30	0.361	0.000	0.34	5.28	0.068	2.20
Helium purged shake	0	-	0.189	0.104	0.54	2.88	-	-
	1	2.30	0.228	0.103	0.70	3.49	0.038	0.77
	3	2.00	0.300	0.000	0.09	4.62	0.007	1.29
	6	2.60	0.247	0.000	0.15	4.76	0.046	1.49
	12	0.50	0.236	0.000	0.17	4.91	0.057	1.66

not helium purged. The soluble inorganic phosphorus concentration increased with time in aerobic samples; however, in helium purged samples the soluble inorganic phosphorus increased for the first three weeks and then decreased during the last nine weeks of incubation. The levels of soluble inorganic phosphorus were significantly higher in aerobic samples which were shaken as compared to those which were static. The soluble organic phosphorus content of all samples tended to decrease with time; however, the rate of decrease of soluble organic phosphorus content during the 11 weeks of incubation was greatest in samples which were shaken. The total soluble phosphorus content of all samples tended to reach a peak value after one week of incubation and then remain relatively constant or decline with time thereafter.

In aerobic samples, the decline in total soluble phosphorus content resulted from more rapid decreases in soluble organic phosphorus than increases in soluble inorganic phosphorus, whereas in helium purged samples soluble organic phosphorus rapidly decreased and soluble inorganic phosphorus increased for three weeks and then decreased giving a net decrease in total soluble phosphorus. During 12 weeks of incubation 3.75 μg and 10.2 g of phosphorus were released to the solution phase from sediment in aerobic samples which were static and shaken, respectively. In helium purged samples 8.55 μg phosphorus per sample was removed from the solution phase during 12 weeks of incubation.

The ammonium content of aerobic static samples and helium purged samples increased during the first week of incubation, decreased to a low level during the next two weeks, and then remained low during the remainder of the incubation period. The ammonium concentration in aerobic shaken samples decreased during the first week of incubation and then slowly increased during the remaining 11 weeks of incubation. The nitrate content of all samples increased rapidly during the initial one to three weeks of incubation and then increased slowly during the remainder of the incubation period. The finding that nitrification was occurring in helium purged samples is good evidence that the samples were not anaerobic and that nitrification is not limited by relatively low dissolved oxygen contents in the water.

The soluble inorganic nitrogen content of samples tended to increase with time throughout the incubation. During 12 weeks of incubation 218, 330, and 249 μg of inorganic phosphorus per sample were released from sediment to the solution phase in aerobic static, aerobic shaken, and helium-purged shaken sample, respectively. This finding suggests that shaking may increase the mineralization of organic nitrogen and that a reduction of dissolved oxygen in water may decrease the mineralization of organic nitrogen.

4.10.3 Effect of Calcium Carbonate Addition

Sediments may contain various concentrations of calcium carbonate and it has been reported that calcium carbonate has the ability to sorb phosphate. However, it has been found that the phosphorus sorption capacity of lake sediments tended to be inversely related to calcium carbonate content. Since eroded soil materials may contain significant amounts of calcium carbonate, it is desirable to study the effects of calcium carbonate on solubility in sediment-water systems.

The effects of adding calcium carbonate on the soluble nutrient levels in creek water samples incubated for 12 weeks is given in Table 89.

TABLE 89
The Effect of Calcium Carbonate on the Level of Soluble N and P

Treatment	Incubation time (weeks)	Concentration of soluble Inorg-P	Org.P	Amm.-N	Nit.-N	Change in concentration during incubation Sol-P	Sol inorg-N
		mg/l					
None	0	0.189	0.104	0.54	2.88	-	-
	1	0.220	0.090	1.15	2.97	0.017	0.69
	3	0.258	0.024	0.21	4.36	0.003	1.14
	6	0.309	0.018	0.21	4.84	0.034	1.63
	12	0.314	0.004	0.10	4.77	0.025	1.44
CaCO3*	0	0.185	0.117	0.57	2.97	-	-
	1	0.203	0.050	0.89	3.11	0.049	0.46
	3	0.260	0.013	0.14	4.81	0.029	1.41
	6	0.270	0.015	0.29	4.64	0.017	1.39
	12	0.289	0.000	0.36	5.20	0.013	2.02

* 2 grams of CaCO3 added per sample.

The finding that addition of large amounts of calcium carbonate did not significantly decrease the initial levels of soluble inorganic phosphorus or soluble organic phosphorus in water samples suggests that calcium carbonate does not sorb soluble phosphorus in samples of Black Creek water. The levels of soluble inorganic phosphorus increased with time in both calcium carbonate amended and unamended samples. The soluble organic phosphorus concentration decreased with time in both amended and unamended samples, but the rate of decrease was more rapid in calcium carbonate amended samples. The total soluble phosphorus content of calcium carbonate amended samples decreased during the first week of incubation and then increased slowly during the remainder of the incubation period. The total soluble phosphorus content of unamended samples increased for the first week of incubation, decreased during the next two weeks, and then increased to a near constant level for the remainder of the incubation period. During the 12 week incubation period, 3.75 μg of phosphorus per sample were released to the solution phase of unamended sample, whereas in calcium carbonate unamended samples, 1.95 μg of phosphorus were removed from solution. The effect of calcium carbonate on the total soluble phosphorus content of water samples was likely due to decreased desorption of inorganic phosphorus from sediment or to decreased mineralization of organic phosphorus by the sediment.

The soluble ammonium content of calcium carbonate amended amples increased during the first week of incubation and then declined to a low level for the remainder of the incubation period. The nitrate concentration increased with time in both calcium carbonate amended and unamended samples. amended and unamended samples. There was little effect of calcium carbonate addition on the apparent nitrification rate in samples. The total soluble inorganic nitrogen content of unamended and calcium carbonate samples increased at about the same rate during the first six weeks of incubation. However after twelve weeks of incubation 216 μg nitrogen were released to the solution in unamended samples whereas 303 μg nitrogen were released in calcium carbonate amended samples.

4.10.4 Addition of Soluble Inorganic Phosphorus

Table 90 gives data on the effects of the initial inorganic phosphorus concentration on the level of soluble phosphorus in creek water subjected to laboratory incubation. Replacement of the liquid phase of the creek water samples with distilled water markedly lowered the initial soluble inorganic phosphorus content and increased the soluble organic phosphorus content of the samples relative to the untreated samples. Addition of organic phosphorus (34 or 84 μg per sample) markedly increased the soluble inorganic phosphorus content of water samples (91 percent and 63 percent of the added inorganic phosphorus remained in solution at the low and high addition rates, respectively). Addition of 34 μg of inorganic phosphorus per sample decreased the level of soluble organic phosphorus, whereas addition of 84 μg phosphorus per sample increased the soluble organic phosphorus concentration. The soluble inorganic phosphorus content of samples whose liquid phase was replaced by water increased with time up to three weeks of incubation and then remained relatively constant for the remainder of the incubation period. The soluble inorganic phosphorus content of samples amended with inorganic phosphorus tended to remain relatively constant with time during incubation. The soluble organic phosphorus content of most samples decreased rapidly during the first three weeks of incubation and then decreased slowly thereafter. In samples amended with 34 μg of inorganic phosphorus the soluble organic phosphorus content increased rapidly during the first week of incubation and then decreased rapidly thereafter. The total soluble phosphorus content of samples whose liquid phase was replaced by distilled water decreased throughout the period of incubation. The total soluble phosphorus content of samples amended with 34 μg of inorganic phosphorus remained relatively constant throughout the incubation period, however, in samples amended with 84 μg of inorganic phosphorus the total soluble phosphorus content decreased markedly for the first three weeks and remained constant.

The fact that the soluble organic phosphorus content of amended samples was decreasing faster than the soluble inorganic P content was increasing suggests that at least a portion of the decrease in organic phosphorus from solution is the result of sorption of organic phosphorus compounds by sediments. During 12 weeks of incubation, the amount of phosphorus lost from solution (sorbed by sediments or immobilized in microbial cells) was 11.4, 2.25, and 22.95 μg of phosphorus per sample for samples with liquid phase replacement, amendment with 34 μg of phosphorus, and amendment with 84 μg phosphorus respectively.

4.10.5 Addition of Soluble Inorganic Nitrogen

The effects of the initial levels of soluble inorganic nitrogen on the concentrations of ammonium and nitrate in creek water samples incubated for 12 weeks is given in Table 91. Replacement of the liquid phase of samples with distilled water markedly reduced the initial concentrations of ammonium and nitrate in incubated samples. Addition of ammonium nitrate (1500 or 6000 g nitrogen per sample) increased the initial concentration of both forms of inorganic nitrogen in solution, although from 12 to 24

TABLE 90
Effect of SIP Addition on the Level of soluble Phosphorus

Treatment	Incubation time (weeks)	Concentration of soluble		Change in concentration of total soluble P during incubation
		Inorg.P	Org.P	
		mg/l		
Deionized Water*	0	0.052	0.181	-
	1	0.125	0.083	-.026
	3	0.179	0.009	-.059
	6	0.171	0.005	-.076
	12	0.157	0.000	-.076
None	0	0.189	0.104	-
	1	0.220	0.090	.017
	3	0.258	0.024	-.013
	6	0.309	0.018	.035
	12	0.314	0.004	.025
34 g P added	0	0.396	0.055	-
	1	0.404	0.040	-.050
	3	0.412	0.025	-.013
	6	0.401	0.008	-.041
	12	0.433	0.002	-.015
84 g P added	0	0.545	0.159	-
	1	0.466	0.174	-.064
	3	0.513	0.029	-.162
	6	0.551	0.014	-.139
	12	0.544	0.007	-.153

* Entire liquid phase of sample replaced with deionized water.

percent of the added ammonium was apparently removed from solution by cation exchange reactions with sediment. The ammonium concentration in samples having their liquid phase replaced with distilled water remained low throughout 12 weeks of incubation. The ammonium concentration in samples treated with ammonium nitrate remained constant for one week and then decreased to very low values during the next two weeks of incubation. The nitrate content of samples having their liquid phase replaced with distilled water tended to increase slowly during the incubation period. The nitrate content of samples amended with ammonium nitrate increased, slowing during the first week of incubation, then increasing rapidly during the next two weeks, and then remained relatively constant throughout the remainder of the incubation period.

The total soluble nitrogen content of samples whose liquid phase was replaced with distilled water tended to increase slightly as a result of incubation indicating that mineralization was slow in that system. The total soluble nitrogen content of samples amended with ammonium nitrate increased significantly during the first three weeks of incubation and then

TABLE 91
Effect of Ammonium Nitrate Addition on the Concentration of Soluble N

Treatment	Incubation time (weeks)	Concentration of soluble		Change in concentration of soluble inorganic N during incubation
		Amm.-N	Nit.-N	
		mg/l		
Deionized Water*	0	0.26	0.28	-
	1	0.21	0.11	-0.21
	3	0.14	0.80	0.40
	6	0.20	0.93	0.58
	12	0.17	0.80	0.44
None	0	0.54	2.88	-
	1	1.15	2.97	0.72
	3	0.21	4.36	1.17
	6	0.22	4.84	1.66
	12	0.10	4.77	1.64
1500 g N added	0	4.36	7.14	-
	1	4.34	7.88	0.71
	3	0.19	13.33	2.00
	6	0.22	13.34	2.05
	12	0.32	13.22	2.03
6000 g N added	0	18.12	21.64	-
	1	18.92	22.89	2.14
	3	0.22	43.06	3.60
	6	0.24	43.20	3.86
	12	0.22	42.95	3.50

* Entire liquid phase of sample replaced with deionized water.

remained relatively constant for the remainder of the 12 week period. The net amounts of inorganic nitrogen formed during 12 weeks of incubation were 66, 246, 305, and 525 μg per sample for samples with liquid phase replacement, no treatment, addition of 1500 g nitrogen, and addition of 6000 μg with liquid phase replacement as compared to untreated samples suggests that a portion of the nitrogen mineralized is soluble organic nitrogen which was lost when the liquid phase was removed. The finding that more nitrogen is mineralized in samples treated with ammonium nitrate than in untreated samples suggests that a "priming effect" of inorganic nitrogen on mineralization may be significant in aquatic systems.

From the data collected during the incubation of the stream samples under various environmental conditions, it can be concluded that there are both long-term and short-term transformations occurring which influence the amounts and forms of nitrogen and phosphorus found in the solution phase.

Short-term transformations appear to be sorption or desorption of both organic and inorganic phosphorus and possibly the release of sorbed phosphorus from soil minerals and dissolution of phosphorus occluded in iron and aluminum. The short-term transformations influencing the nitrogen and organic phosphorus contents of water are much more dependent upon the factors affecting microbial growth since transformations are largely carried out by microorganisms. Microbiological transformations may occur in very short periods of time if conditions are favorable for organisms or long periods when conditions are unfavorable. The short-term processes involving inorganic phosphorus transformations are more physiochemical in nature and therefore not so dependent on environmental factors.

The long-term processes involved in nitrogen and phosphorus transformations in water systems are likely to be the mineralization of organic nitrogen and phosphorus components in solution and in the sediment. Based on data obtained in this study, mineralization processes appear to be major long-term processes leading to higher soluble nitrogen and phosphorus concentrations in incubated samples.

The soluble inorganic phosphorus concentration in most samples increased slowly with time during the incubation period. It appears this increase in soluble inorganic phosphorus was due mainly to the mineralization of soluble and sediment organic phosphorus. During the mineralization process the sorption-desorption process controls the equilibrium obtained between the sediment and solution.

In aquatic systems amended with calcium carbonate the concentration of total soluble phosphorus remained relatively constant indicating that calcium carbonate may decrease mineralization of sediment organic phosphorus. Increased content of dissolved oxygen and shaking of samples increased the concentration of soluble inorganic phosphorus and decreased the concentration of organic phosphorus. The overall effect was an increase in total soluble phosphorus during the incubation.

Addition of inorganic phosphorus to samples released organic phosphorus into solution most likely by replacement of organic phosphorus compounds sorbed on soil colloid surfaces by added inorganic phosphorus. The total soluble phosphorus content of samples treated with inorganic phosphorus decreased during the 12 week period indicating that soluble organic phosphorus was sorbed by the sediments. The samples in which the solution was replaced by deionized water were unable to attain the original concentration of inorganic phosphorus by desorption processes and part of the soluble organic phosphorus present in the liquid phase was sorbed by the sediment.

A 33 degree C incubation temperature increased the rate of mineralization of phosphorus and increased the final total soluble phosphorus concentration by a significant amount. A 5 degree C incubation temperature decreased the rate of mineralization of organic phosphorus.

The treatments applied which would increase microbial growth also enhanced the mineralization of nitrogen and as a final result the concentration of nitrate-nitrogen in solution increased. Aeration, calcium carbonate amendment, increased temperature and the addition of ammonium nitrate all had positive effects on the mineralization of nitrogen and the final total soluble inorganic nitrogen concentration. Low temperature seemed to have the greatest negative effect on the concentration of soluble inorganic nitrogen, but there were still increases in the solution concentration over the 12 week incubation period.

STUDY RESULTS

4.11 ALGAL STUDIES

4.11.1 Introduction

The importance of phosphorus contamination of natural waters has received an enormous amount of attention in past years. One reason for this amount of investigation has been the "algal bloom" effect of increasing phosphorus additions to water which normally did not contain concentrations of phosphorus capable of supporting excessive photosynthetic biomass. The short-term effects of an algal bloom range from a degeneration in the quality of drinking water by algal exudates and physical fouling of water treatment facilities, to the impairment of enjoyment of recreational waters by odorous decomposition of senesced cells, direct inducement of fish kills, and depletion of aquatic aesthetic value. The long-term effect of an algal bloom is the acceleration of eutrophication.

The dissolved orthophosphate ion is the most available form of P to algae (Vollenweider, 1970). However, in the past, the comparison of chemical analysis of orthophosphate to algal availability of the ion has given variable results. Therefore, the determination of algal available soluble P is the only dependable method of ensuring knowledge of a water sample's potential for supporting biomass. The most frequently used method for accurately determining available soluble P is the algal bioassay method developed by the U. S. Environmental Protection Agency called the Provisional Algal Assay Procedure Bottle Test (PAAP). (1971).

In lake systems the amount of soluble orthophosphate in the water phase is a function of the equilibrium between the inorganic P bound on the sediment and the interstitial dissolved inorganic P (Syers et al, 1973). Dissolved inorganic P can, therefore, be released to the overlying water column when the concentration of interstitial dissolved inorganic P exceeds that in the water column. Because of the dynamic equilibrium existing between sediment and solution, the sediment of a lake system is ultimately a P reservoir capable of replenishing inorganic P taken up by aquatic organisms.

Sediments normally contain large quantities of amorphous, hydrated iron oxides capable of sorbing P. Sorbed P in sediments is capable of mobility within the system and rapidly sorbing or desorbing in response to small changes in P concentration. Therefore, the potential for P release in response to uptake within the system is of importance and in essence will dictate the quantity of supportable biomass.

Determination of the fraction of sediment P available to algae is very difficult. Although dialysis systems have been used in the past with limited success, a method developed by Sagher and Harris (1975) incubates algal cells intimately with sediment and enables the determination sediment P fraction capable of supplying P for algal uptake. The Sagher-Harris method was selected for use in this study.

The objectives of this study were:

1. To determine the availability to algae of soluble and sediment-

bound P in water samples collected from the Black Creek watershed, and

2. To determine the sediment P fraction (ammonium flouride, NaOH, and HCl extractable) of sediment-bound P which is most available to algae.

4.11.2 Materials and Methods

4.11.2.1 PAAP BOTTLE TEST

An algal bioassay was conducted to determine the available portion of soluble P in water samples obtained from seven sites within the Black Creek watershed on March 28 and June 30, 1977. The bioassay method used was the PAAP Bottle Test (USEPA, 1971). The method finds its roots in Liebig's Law of the Minimum which states that "growth is limited by substance that is in minimal quantities in respect to the needs of the organism." That is, if one nutrient is lacking, the organism's limit for growth (in this case, reproduction) is determined by parameters set by the amount of limiting nutrient. Therefore, the PAAP method used created a reference curve which related the number of cells (or growth rate) of a test alga to the concentration of the nutrient being tested, phosphorus, in an inoculated growth medium in which no other factor is limiting. The cell numbers of the inoculated water sample were determined and the numbers compared to those found in the reference medium to ascertain the corresponding concentration of available P. In addition to inoculating the unamended water samples, three additional treatments were used to attempt a more complete evaluation of limiting nutrients in Black Creek drainage water. The treatments used were (1) a P spike of 0.1 mg/l to ensure that P would not be limiting maximal cell reproduction, (2) a micronutrient spike equal to that found in the PAAP reference medium to measure the response of the test organism to added micronutrients, and (3) a combination spike of 0.1 mg P/l plus micronutrients equal to that found in the reference medium in order to create a non-limiting growth medium.

The bioassay was conducted in a 250 ml Erlenmeyer flask containing 60 ml of the PAAP medium or the water sample. The standard PAAP reference medium contained between 0.0 and 0.2 mg P/l (0.000, 0.005, 0.015, 0.050, 0.075, 0.100, 0.200 mg P/l). Cell counts were made initially and at 24 hour intervals until a constant, positive relationship existed between cell numbers and P concentration (after three days of incubation for all studies conducted) at which time the cell densities of inoculated water samples were counted and the available P concentration determined by reference to the standard growth curve.

4.11.2.2 AVAILABILITY OF SEDIMENT-BOUND P

In determining the biologically available sediment-bound P, studies were conducted on the amounts of sediment-bound P sequentially extractable with ammonium flouride, NaOH, and HCl before and after incubating with algal cells for two weeks under optimum growth conditions. Decreases in extractable P in sediments resulting from incubation were assumed to be that P immobilized into cells during algal growth. All sediment P values were corrected for the amounts of algal P in the system which were extracted during the sequential extraction procedure.

All sediment bioassay studies were carried out in 250 ml Erlenmeyer flasks using 60 ml of standard medium containing sufficient sterile sediment to provide 0.62 mg P/l. Flasks were inoculated with Selenastrum capricornutum (10,000/ml), incubated at 24 degrees C for 2 and 4 weeks, cell densities determined, and the entire contents of duplicate flasks were subjected to sequential extraction and P determination.

4.11.3 Results and Discussion.

4.11.3.1 AVAILABILITY OF SOLUBLE P

A study was conducted to determine the availability of soluble phosphorus to algae in water samples from seven sites within the Black Creek watershed. The method employed was a modification of the Provisional Algal Assay Procedure Bottle Test (USEPA, 1971) to provide a rapid assay of available soluble P.

S. capricornutum exhibited a typical sigmoid growth rate in the reference medium at P concentrations of 0.05 mg/l or greater. The stationary phase of growth began after 96 hours of incubation for all treatments, but at lower cell densities for each decrease in P concentration.

The reference curves produced by plotting cell numbers after three or four days versus initial P concentration gives a leveling off of cell numbers at P concentrations greater than 0.1 mg/l. The leveling off above 0.1 mg P/l may be looked upon within the experimental system as the critical level of P or that concentration at which nearly maximum cell production takes place.

Table 92 presents concentrations of soluble inorganic P (SIP) and total soluble P (TSP) analytically determined in the March and June samples, as well as the amount of available P detected by the bioassay using cell counts as the determinative criteria in amended and unamended samples. In all but one sample, the quantity of soluble orthophosphate determined by chemical analysis was greater in March as compared to June samples.

The same trends were observed for the quantity of TSP in water samples.

Also indicated is the fact that in no case did the quantity of P determined as available by the bioassay procedure exceed that detected chemically as SIP. The chemical analysis of SIP, therefore, detected P components which were unavailable to S. capricornutum in unamended water samples during three to four days of incubation. These components may soluble polyphosphates or hydrolyzable organic P esters.

The available P detected in the unamended samples averaged 0.096 mg/l (nearly maximal biomass production) in March samples and 0.033 mg/l in June samples (indicating cell production was limited by P). The range in available P was 0.076 to 0.128 mg P/l and 0.012 to 0.049 mg P/l for March and June samples, respectively.

Results of March samples receiving the P spike seem to bear out the fact that P was not limiting cell production. However, data from the June samples indicate a response to P addition, but in most cases cell densities did not reach maximal values observed in reference curves. The finding

TABLE 92
Availability to Algae of Soluble Phosphorus in Stream Water

	P Concentration in Water		Available P in Water Samples as Determined from Cell Count Bioassay of:*			
Site #	SIP	TSP	U	P	MN	PMN
	--------	--------	---μg P/ml---	--------	--------	--------
March:						
2	.106	.123	.080	.084	.094	.090
3	.121	.150	.076	.044	.106	-
4	.121	.139	.116	.098	.116	-
5	.171	.173	.128	.106	.099	-
6	.259	.280	.102	.068	.096	.081
12	.135	.153	.086	.068	.116	-
14	.131	.148	.083	.094	.132	-
Ave	.149	.166	.096	.080	.108	.085
June:						
2	.069	.100	.035	.018	.041	.061
3	.038	.063	.016	.036	.019	-
4	.045	.075	.033	.042	.043	.088
5	.053	.072	.040	.080	.046	-
6	.072	.091	.045	.099	.044	.085
12	.047	.062	.012	.081	.020	.032
14	.161	.190	.049	.045	.257	-
Ave	.069	.093	.033	.048	.067	.066

* U, unamended water sample; P, water sample spiked with 0.1 mg P/l; MN, water spiked with micronutrients; PMN, water samples spiked with phosphorus (0.1 mg P/l) and micronutrients.

could be an indication that another nutrient was limiting algal growth.

The averages of the March and June samples spiked with micronutrients gave growth responses over both the unamended and P spiked samples. That is, the organisms incubated in the water sample were able to utilize more P as a result of being supplied with additional micronutrients. This growth stimulation from micronutrient addition occurred in four of seven March samples and two of the seven June samples.

The P plus micronutrient spike gave positive growth responses in five of six samples treated, but in no case was the available P detected by bioassay equal to the 0.1 mg P/l added. This is an indication of a limiting concentration of micronutrients or P, or both, which upon adding P and micronutrients disappeared until growth was limited by another nutrient.

A comparison was made (Table 93) between amounts of available soluble P detected by bioassay in water samples from groups of sites which differ in their land use characteristics. In the March sample, the soluble P determined by bioassay to be available was greatest in the rural-urban portion of the watershed. The June samples showed the greatest available P concentration in samples collected from the rural-urban portion of the watershed and the Maumee River.

TABLE 93

Variation of Available Soluble Phosphorus by Adjoining Land Use Characteristics

Site #	Sampling Time March	 June
	Available Soluble P (μg/l)	
	Rural Portion	
2	.080	.035
3	.076	.016
4	.116	.033
Ave	.091	.028
	Rural-Urban Portion	
5	.128	.040
6	.102	.045
Ave	.115	.042
	Entire Watershed	
12	.086	.012
	Maumee River	
14	.083	.049
*Ave	.096	.033

* Includes available soluble P from all sites sampled.

4.11.3.2 AVAILABILITY OF SEDIMENT-BOUND P

A study was conducted to evaluate the availability of sediment-bound phosphorus to algae in suspended sediments collected from seven sites within the Black Creek watershed. A modified version of the method developed by Sagher and Harris (1975) was employed. This method is a combination chemical and biological assay which fractionates the forms and quantities of available P present. Only data from the two week incubation time is reported.

The proportion of total sediment P immobilized by algae from each sample during a two week incubation and the final density in each sample are shown in Table 94. In March samples an average of 18.1% of total sediment P was available to algae and the range in availability was from 10.5 to 27.7%. The available P in the June samples averaged 21.1% of the total sediment P with a range from 10.5 to 30.0%. These results tend to be higher than some other previously measured values (Wildung and Schmidt, 1973) and lower than others (Sagher and Harris, 1975).

Table 95 presents the final cell densities and the available P as a percent of the sediment inorganic P (Pi) after incubation for two weeks.

TABLE 94
Proportion of Sediment Phosphorus Immobilized by Cells

	Sampling Time			
	March		June	
Site #	Cell Density x10-6/ml	Available P as % of Total	Cell Density x10-6/ml	Available P as % of Total
2	8.529	14.7	5.175	10.5
3	9.599	19.4	8.551	20.2
4	4.242	10.5	5.954	16.8
5	5.225	27.7	5.000	16.6
6	6.500	20.6	6.591	29.0
12	-	-	5.900	24.6
14	-	-	8.408	30.0
Ave	6.819	18.6	6.511	21.1

The averages of the March versus June samples show an increase (26.9 vs. 33.1%, respectively) in the percent of sediment Pi of which become available after two weeks of incubation. This suggests that a higher percentage of sediment Pi is available to algae during storm events with low sediment transport (June sample) as compared to more intense storms with more soil erosion.

TABLE 95
Proportion of Sediment Inorganic Phosphorus Immobilized

	Sampling Time			
	March		June	
Site #	Cell Density x10-6/ml	Available P as % of Pi	Cell Density x10-6/ml	Available P as % of Pi
2	8.529	26.6	5.175	26.7
3	9.599	27.9	8.551	29.0
4	4.242	15.0	5.954	34.1
5	5.225	34.7	5.000	31.1
6	6.500	30.7	6.591	37.7
12	-	-	5.900	32.7
14	-	-	8.408	40.9
Ave	6.819	26.9	6.511	33.1

The average proportions of Pi to become available are again slightly higher than Wildung and Schmidt (1973) reported in lake sediments. The percentage of the total available P derived from each inorganic Pi fraction is presented in Table 96.

TABLE 96

Proportion Immobilized by Cells Originating from Certain Extractable Fractions

	Sampling Times							
	March				June			
		Inorganic P Fraction Extracted By				Inorganic P Fraction Extracted By		
Site #	Available P μg P/flask	Amm.F	NaOH	HCl	Available P μg P/flask	Amm.F	NaOH	HCl
		% of Available Pi				% of Available Pi		
2	3.45	33.1	39.2	27.7	4.03	73.3	7.0	20.6
3	4.70	43.7	47.0	9.3	4.54	28.2	36.6	35.1
4	2.62	22.9	0	77.0	4.63	32.5	67.5	0
5	6.84	36.6	38.8	24.5	3.73	51.6	48.2	0
6	4.84	52.0	40.7	7.2	8.21	43.6	39.0	13.6
12	-	-	-	-	6.51	32.4	49.4	18.2
14	-	-	-	-	6.40	61.8	28.0	10.2
Ave	4.49	37.7	33.1	29.1	5.44	46.2	40.8	14.0

On an average, in both March and June samples, the highest proportion (37.7 and 46.2%, respectively) of the available Pi originated in the ammonium flouride extractable fraction (range was 22.9 to 57.0%, and 28.2 to 73.3% respectively). Ranking second in availability is NaOH extractable fraction which contributed an average of 33.1% and 40.8% of the available Pi in March and June samples, respectively. The HCl extractable fraction also contributed to available P in both the March and June samples (29.1 and 14.0% respectively). This finding suggests that all Pi fractions in sediment are at least partially available to algae, however, the aluminum and iron bound P fractions (ammonium flouride and NaOH extractable) seem to be the most important.

Table 97 compares the proportion of Pi which becomes available after two weeks in sediments from sites with differing land use characteristics. There was a higher proportion of Pi which was available in the samples from the rural-urban portion of the watershed as compared to those from the rural portion (over 9% greater in March and 4% in June samples). In addition, the highest proportion of available Pi was observed in the June samples taken from the Maumee River site. Most of the available sediment Pi originated in the ammonium flouride extractable fraction (Table 95).

4.11.4 Conclusions

4.11.4.1 AVAILABILITY OF SOLUBLE PHOSPHORUS

To study the availability of soluble P to algae a modification of the PAAP Bottle Test was used and provided a consistent, positive relationship between cell numbers and P concentration.

The soluble P determined as available by bioassay for all sites sampled and both sampling times was always less than that measured chemically as SIP and TSP. Algal growth in June samples was limited by low

TABLE 97
Variation in Sediment Inorganic P Immobilized by Source of P

Site #	Sampling Time March	 June
	Available P as % of inorg.P	
	Rural Portion	
2	26.6	26.7
3	27.9	29.0
4	15.0	34.1
Ave	23.2	29.9
	Rural-Urban Portion	
5	34.7	31.1
6	30.7	37.7
Ave	32.7	34.4
	Entire Watershed	
12	-	32.7
	Maumee River	
14	-	40.9
*Ave	26.9	33.1

* Includes values available from all sites.

concentrations of available P, but in most cases some nutrient or factor other than P or micronutrients also limited growth. In addition, the rural-urban portion of the watershed contained higher levels of available P than did the rural portion in both March and June sampling periods.

4.11.4.2 AVAILABILITY TO ALGAE

Algal growth was shown to be limited by P in treatments in which the sediment was the sole source of P. However, the sediments did supply in most cases sufficient P to support substantial growth of S. capricornutum. The proportion of total sediment P which became available in the March and June samples were 18.6 and 21.1%, respectively, and the proportion of Pi which became available was 26.9 and 33.1%, respectively. The largest portion of the available P originated in the ammonium flouride extractable fraction, while both the NaOH and HCl extractable fraction contributed to the total available P pool. Sediments from the rural-urban portion of the watershed had higher proportions of the Pi available for algae as compared to agricultural portions. Maumee River sediment from the June sampling displayed the highest (40.9%) proportion of Pi as available to algae.

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4.12 STUDIES OF MAUMEE BASIN

The annual precipitation for the Maumee River Basin and the annual sediment yield and discharge from the Maumee River into Lake Erie for a ten-year period, October 1961 to October 1972, are presented in Table 98.

TABLE 98
10-Year Annual Precipitation Sediment Yield and Discharge

Year	Precipitation* (mm)	Discharge (mm over basin)	Ratio of Discharge to Precipitation (%)	Sediment Yield (kg/ha)
1970-71	739	198	27	304
1969-70	898	267	30	609
1968-69	938	320	34	662
1967-68	980	345	35	989
1966-67	835	348	42	763
1965-66	807	181	22	202
1964-65	826	196	24	516
1963-64	716	150	21	427
1962-63	656	109	17	159
1961-62	683	186	27	323
Average	808	230	28	495

*Average of three locations: Fort Wayne, Defiance and Toledo.
This table is based on data provided by the U.S. Environmental Data Service and the U.S. Geological Survey.

The annual precipitation for the 10-year period seems to be part of some cyclical pattern. Less than normal precipitation occurred from 1961 to 1966 and above normal precipitation from 1967 to 1971. The years with the highest precipitation had the highest runoff and also the highest percentage of precipitation occurring as runoff. As a consequence, the average annual sediment yield for the last five years was 665 kg/ha, more than twice the 325 kg/ha yield for the first five years.

Monthly precipitation patterns at Fort Wayne in the western part of the Maumee River Basin, at Defiance in central part, and at Toledo in the eastern part near the mouth of the river are shown in Figure 31 for the ten-year period. Low precipitation months are October, February and for the growing season, August. High precipitation months are usually April, May, June and July.

The average monthly discharge of the Maumee River given as a depth over the basin and the sediment yield on an area basis are shown in Figure 32.

Comparison of the monthly patterns of discharge and sediment yield shows a disproportionally high sediment yield occurring in December. Usually the first winter storm of any magnitude carries a high concentration of sediment. The winter storms are generally frontal storms which may be basin-wide. Much of the sediment is already deposited in the channels or lower portions of slopes from localized, convective-type storms which occurred in the spring and early summer months. While the intensity of the localized storms may be high, they often do not have an areal coverage which is great enough to cause significant flow in the major streams of the basin. During the six-month period, June through November, only 16 percent of the total flow and 8 percent of the sediment yield occurred for the 10-year period. On the other hand, the six-month period, December through May, had 84 percent and 92 percent of the total flow and sediment yield, respectively.

In general, those months with the highest discharge or runoff are also the months with the highest sediment yield. For the years with relatively high precipitation, the highest sediment yield usually occurs in December or early January or later in February and early March; for the years with low precipitation, the highest sediment yields are likely to occur in March or April.

The average annual sediment yield of nearly 500 kg/ha from the Maumee River into Lake Erie is not large when compared to many river basins. However, considering the special nature of the receiving body of water yields of this magnitude may still have a detrimental impact. Although this yield is caused by much larger field erosion rates, these rates may yet be within the natural restoration limits of most of the basin soils. The sediment load also consists mostly of suspended particles with a high colloidal fraction. Streams in the basin tend to remain murky even during low flow. And sediment plumes often extend 60 km or more into Lake Erie.

4.12.1 Sources of Sediment

The major sources of sediment from agricultural watersheds in the Maumee Basin are cultivated fields which are subject to rainfall impact and runoff turbulence. Ditch bank sloughing and channel scouring probably account for less than five percent of the total sediment load. Tile drains in some sections of the Maumee Basin have been reported to discharge substantial amounts of sediments into ditches or streams. However, in the Black Creek Watershed, only about one to two percent of the total sediment

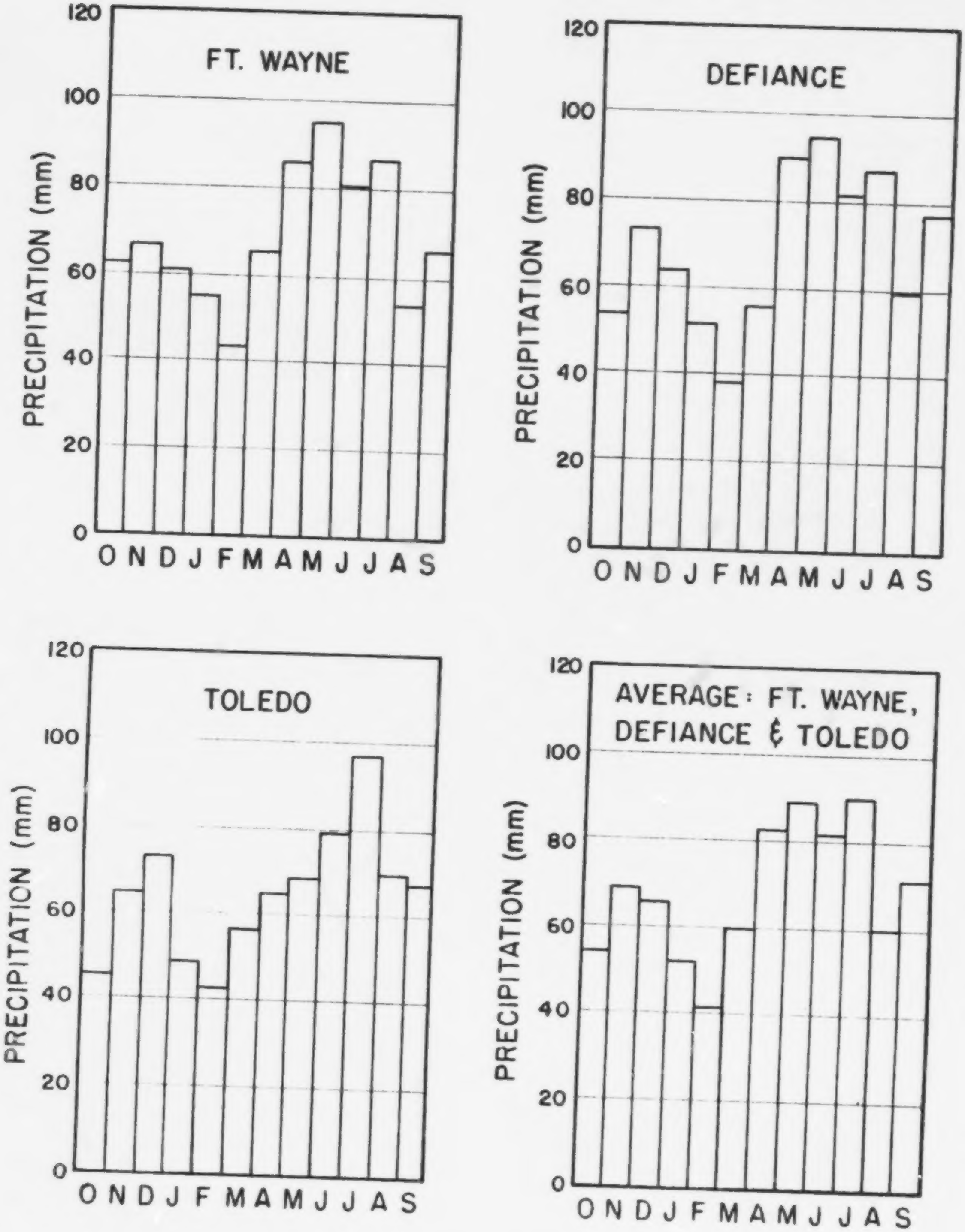
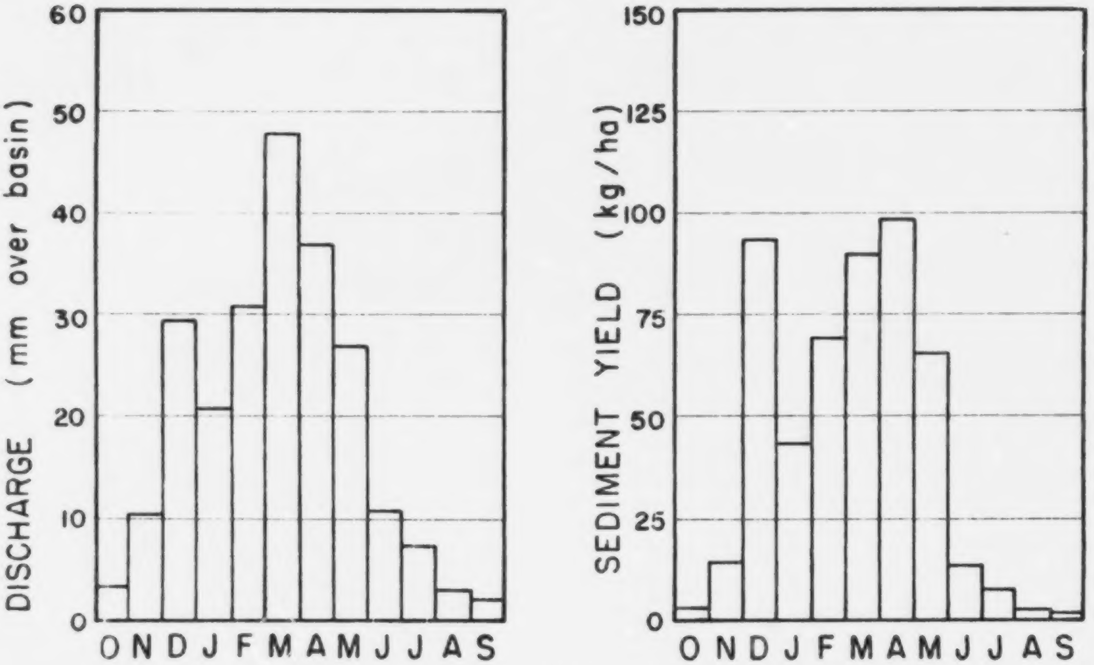


Figure 31. Monthly Precipitation Pattern -- Fort Wayne, Defiance, Toledo



(a) Average monthly discharge (left) and sediment yield (right)

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S
71	2	4	9	3	30	21	4	15	8	2	1	1
70	2	12	4	3	14	16	24	15	3	4	2	1
69	1	3	9	27	15	5	15	11	6	6	1	1
68	1	3	25	7	17	9	8	13	9	4	3	1
67	-	7	32	4	11	21	11	10	2	1	1	-
66	6	3	15	13	8	12	8	22	3	7	2	1
65	-	1	1	7	16	31	30	8	2	1	1	2
64	-	1	-	2	1	28	49	9	7	1	1	-
63	1	1	1	1	2	58	17	4	8	4	2	1
62	2	5	2	18	14	44	6	4	2	1	1	1

WATER YEAR	O	N	D	J	F	M	A	M	J	J	A	S
71	-	1	4	1	45	21	1	17	8	1	-	-
70	1	11	-	-	8	11	33	31	1	2	1	-
69	-	-	15	32	16	2	17	9	4	4	-	-
68	-	-	41	6	11	4	10	20	6	1	-	-
67	-	8	50	-	7	16	8	10	-	-	-	-
66	5	1	13	15	9	8	7	30	-	11	-	-
65	-	-	-	3	35	23	36	2	-	-	-	-
64	-	-	-	-	-	28	67	2	2	-	-	-
63	-	-	-	-	-	85	10	-	3	1	-	-
62	-	1	-	30	11	54	1	1	1	-	-	-

(b) Monthly percentage of yearly discharge (left) and sediment yield (right)

Figure 32. Average Monthly Discharge

yield originates from tile drainage systems. Even though yields from tile drains are relatively small, it should be pointed out that the discharged sediments are mostly colloidal and are delivered directly to ditches or streams for ready transport.

The potential for rainfall and field runoff to cause erosion correlates closely with a statistic consisting of the product value of two rainstorm characteristics, namely, the total kinetic energy of a storm and its maximum 30-minute intensity. This statistic, called the erosion index, allows for comparisons of the annual erosion potential of rainfall and field runoff between different regions and for the determination of the distribution of the annual erosion potential within a region. For instance, the annual erosion potential for the Maumee River Basin is only one-fourth of the erosion potential for lands in the United States near the Gulf of Mexico. Of greater interest, however, is the distribution of the annual erosion potential for the Maumee River Basin. The distribution, in general, follows an S-shaped curve in which 80 per cent of the annual erosion potential occurs in the five-month period, May through September.

May and June are particularly critical months as far as soil erosion is concerned. This is the time when seed beds are prepared and new crops established. In the Black Creek Watershed, over 70 percent of the annual sediment load into the Maumee River occurred during these months in 1975. For the year, the total sediment yield from the watershed was about 2400 kg/ha. However, 1976 was an abnormal year with very little runoff during May and June. Only about 2 percent of the annual sediment yield occurred during these months and quite predictably the sediment yield for 1976 was low averaging about 500 kg/ha.

The erosion-sedimentation process in a river basin can, in general, be divided into upland and in-channel phases. The upland phase is closely related to rainfall events [illegible] the nature of the receiving land area. Major variables are the [illegible] of slope and slope length; surface cover; soil type, tilth, and water content; and the rainfall pattern, intensity, duration, and amount. Temperature may also be an important variable in areas where a significant number of freeze-thaw cycles occur. Erosion is a selective process. Runoff from eroded land will usually contain a progressively higher percentage of smaller particles than the original soil mass. The in-channel phase is little influenced by rainfall and is dependent mostly on the nature of the bed material and the transport capacity of the flow. In this phase, the channel flow can usually transport all the fine material supplied.

The Black Creek Watershed is an upland area. Sediment yield has been monitored and some portions of the watershed have been modeled. However, neither the actual or modeling results can be extended to the Maumee Basin as a whole. On a long term basis, we might reasonably assume the major streams in the basin to be in dynamic equilibrium so that the annual sediment discharged into Lake Erie, except for man-made traps, equals the average annual sediment yield from the upland areas into the main channels. The average sediment yield into the main channels of the Maumee Basin might be predicted if more watersheds similar to the Black Creek Watershed are selected so that the soil, topographic, and land use conditions of the basin are adequately represented and then a random generation of storms representative of an average year is applied to the Basin.

STUDY RESULTS

4.13 CONSTRUCTION, LAND USE DIFFERENCES

Two sets of data are included in this section. The first illustrates water quality differences arising because of small scale differences in land use. The second shows the impact of construction activities on water quality.

On 28 March 1977 four discrete watershed areas (3 at 100 acres, 1 at 500 acres) of the Dreisbach Drain were sampled following a 1.5 inch rainfall. At the outlet of each watershed, four grab samples were collected at one-half hour intervals. No estimates of discharge were made, and only concentration data are reported here. Samples were analyzed by the Illinois Natural History Survey Laboratory. General land use, soils and slopes were as nearly identical as could be expected under field conditions. However, there were differences in conservation practices applied to the four areas: watersheds A and B had no conservation practices applied, watershed C was treated with an extensive terrace system and the largest watershed, D, contained a grass waterway and a variety of other practices, including terraces.

Water quality parameters that differed significantly among the four watersheds are shown in Table 99. Dissolved solids and nitrate were lowest from watershed A, moderate from B and D, and highest from C. The tile outlet of the terrace system was enriched with dissolved ions and soluble nitrogen. Factors responsible for this observation may include the greater leaching of soluble ions due to the subsurface tile drainage acting alone or in combination with heavier fertilizer application within this watershed.

TABLE 99
Differing Parameters, Four Watersheds

Watershed	Dissolved Solids	Nitrate	Sediment (Total Residue)
	mg/l		
A	126 +- 4	2.2 +- 2.0	300 +- 65
B	185 +- 10	6.4 +- 1.1	1700 +- 458
C	250 +- 7	8.8 +- .2	700 +- 87
D	170 +- 10	3.8 +- .5	500 +- 71

Sediment (total residue) concentrations also were lowest from watershed A, moderate from C and D, and highest from watershed B. Again the factors responsible for these differences are complex and cannot be precisely identified. In this situation other land use factors besides conservation practices seemed to exert the greatest influence on water quality. Watershed A had a high percentage of cropland with vegetative cover, including the field immediately upstream from the sampling point, and had the lowest sediment concentration. Conversely, watershed B had a lower percentage of cropland with vegetative cover, including a fall plowed field immediately upstream from the sampling point, and had the highest sediment concentrations. The two watersheds with conservation practices installed had sediment concentrations between these two extremes. To conclude, this small data set illustrates differences in the concentrations of some water quality parameters resulting from small differences in land use. Such data cannot establish cause-effect relationship between land use and water quality, but are useful tests of the principles established through more controlled experimentation.

Ten discrete watershed areas (350-550 acres) were sampled on 3 March, 4 March, 28 March and 23 April, 1977. At the outlet of each watershed two samples were collected at two hour intervals on each of the sampling dates. All sampling was done during moderate runoff events caused by one to two inches of rainfall. Again only concentration data are reported and analysis was conducted by the Illinois Natural History Survey Lab. Soils and slopes differed considerably among the ten watersheds while general land use and application of conservation practices differed to a lesser degree. All these watershed characteristics certainly influence surface runoff water quality, so an evaluation of the interactions of such a complex set of variables with a small data set is difficult. However, the data reveals a striking parallel between high sediment concentrations and recent construction activities (jobs completed in September 1976).

To facilitate an easier pair-wise comparison of sediment concentrations among the watersheds a sediment index was formed. Watershed 1 was consistently assigned an index value of 1.00. Index values for other watersheds (2-13) were formed by dividing the sediment concentrations of watersheds 2-13 by the sediment concentration of watershed 1. This was done separately for all eight sampling intervals. The average sediment indexes and standard deviations of the ten watersheds are shown in Table 100. Well established grass waterways tended to have the lowest sediment indexes (1.0-1.6) and therefore had relatively low sediment concentrations. Stable open ditches with good vegetative cover had higher index values (1.6-3.0).

TABLE 100
Sediment Concentration Indexes - Subwatersheds

Watershed Name	No.	Channel Classification	Average Sediment Index	S. D.
Dreisbach	1	Grassed waterway	1.00	0.00
Wertz	5	(upland)	1.62	0.40
Richelderfer	2	Stable open ditch	1.59	0.30
West Gorrell	3	(upland)	2.01	0.30
East Gorrell	4		3.04	1.19
Smith-Fry	7		1.91	0.65
Lake	11	Stable open ditch	2.09	0.53
Killian	13	(lake bed)	2.32	1.36
Wertz Branch	6	Reconstructed open	7.85	3.33
Fuelling	12	ditch	3.71	1.71

The East Gorrell watershed had the highest sediment index among the stable open ditches. It is significant to note that a major in-channel erosion control structure (drop structure) washed [illegible] on this ditch in the spring of 1977. Failure of this structure resulted in rapid erosion of the upstream channel as the excessive grade attempted to re-stabilize. The data indicate that this process raised the sediment concentration of the stream by 50% compared to the adjacent West Gorrell drainage. Recently reconstructed open ditches with poor vegetative cover had the highest index values (3.7, 7.9). The ditch banks were an obvious source of sediment and the sampling reveals that in-stream sediment concentrations were elevated 4-8 times above the levels in surrounding streams. The large sediment export from the Wertz Branch Ditch altered fish populations in the Wertz Woods.

It is generally agreed that construction activities greatly accelerates soil erosion. Evaluating the degradation of water quality by construction site runoff was not specifically addressed in the Black Creek project. However, in a grab sampling program of ten watersheds, construction associated disturbances were an identifiable influence on water quality (sediment concentrations). These findings raise concerns about temporary negative effects on water quality created by the installation of some soil conservation measures.

In the situations described above, the post-construction precautions against erosion (seeding, mulching, etc.) were certified to meet SCS specifications. However, an extremely dry fall resulted in very poor vegetative cover so that erosion was greater than normal. Regardless, the concerns about water quality degradation remain justified. Both near-site and downstream changes in the stream ecology could damage aquatic resources.

To lessen the environmental impact of conservation practice installation, planners and field technicians need to be aware of stream reaches with aquatic resource potential. In cases where aquatic resources are judged worth protecting, more stringent precautions should be taken to minimize construction damages. Personnel training programs stressing basic ecological principles may be the shortest route to achieving maximum water quality benefits from soil conservation practices.

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SECTION V

Discussion

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5.3	Local Variations in Water Quality	J. Karr D. Dudley	272

5.1 IMPACT OF LAND TREATMENT

The cost of land treatment in the Black Creek Watershed was not trivial.

Costs by practice are included in Table 101. Total costs listed in the table include contributions of individual landowners. These totaled nearly $150,000 for the project.

Also included must be the cost of technical assistance furnished under the grant by the Soil Conservation Service. Soil Conservation Service costs are listed in Table 102.

TABLE 101
Cost by Practice

PRACTICE	UNIT	GOAL	ACCOMP-LISHMENT	% OF GOAL ACCOM	TOTAL COST (Includes Landowner Costs)	% OF COST SHARE	DISTRICT PAYMENT	TOTAL UNIT COST	DISTRICT UNIT COST
District Cooperators	No	148	141	95					
Conservation Plans	No	170	133	78					
Landowner-District Contracts	No	148	119	80					
Group Contracts	No		19						
Land Adequately Treated	Ac	10,573	7,975	75			518,876.59		65.05
Land Adequately Protected	Ac		10,025				518,876.59		51.75
Conservation Cropping System	Ac	7,418	6,548	88	$5,948	70	4,164.00	0.90	0.63
Contour Farming	Ac	769	10	1	20	80	16.00	2.00	1.60
Critical Area Planting	Ac	10	15	150	3,440	80	2,752.57	229.38	183.50
Crop Residue Management	Ac	7,491	2,952	39	3,857	65	2,507.15	1.30	0.84
Diversions	Ft	39,200	1,860	5	1,906	70	1,334.81	1.02	0.71
Farmstead Windbreaks	Ac	75	4	5	386	75	289.79	96.59	72.44
Field Border	Ft	288,320	132,688	46	38,071	70	26,650.30	0.30	0.20
Field Windbreak	Ft	12,000	0	0	0	70	0.00	0.00	0.00
Grade Stabilization Structure (including tile outlet CMP)	No	368	516	140	105,527	75	79,145.91	294.51	153.38
Grassed Waterway	Ac	68	64	94	48,332	80	38,666.21	755.19	604.15
Holding Ponds & Tanks	No	11	10	91	45,120	50	22,560.09	4,512.01	2,256.00
Land Smoothing	Ac	300	0	0	0	70	0.00	0.00	0.00
Livestock Exclusion	Rd	2,050	15,869	77	12,795	70	8,956.82	0.80	0.56
Livestock Watering Facility	No	28	7	25	1,715	70	1,200.50	245.00	171.50
Minimum Tillage	Ac	7,656	690	9	2,679	80	2,126.65	3.88	3.10
Pasture Management	Ac	402	97	24	1,416	65	920.40	14.59	9.48
Pasture Planting	Ac	501	112	22	10,695	70	7,486.72	95.49	66.84
Pond	No	39	10	26	20,740	60	12,444.21	2,074.03	1,244.42
Protection During Development	Ac	118	4	3	313	65	203.62	78.31	50.90
Recreation Area Improvement	Ac	12	10	83	1,187	50	593.81	118.76	59.38
Sediment Control Basins	No	6	3	50	5,931	75	4,448.90	1,977.29	1,482.96
Stream Channel Stabilization	Ft	6,000	16,093	268	127,660	80	102,128.51	7.93	6.34
Streambank Protection	Ft	122,000	99,304	81	78,682	70	55,077.40	0.79	0.55
Stripcropping	Ac	300	0	0	0	80	0.00	0.00	0.00
Surface Drains	Ft	90,500	9,396	10	3,741	65	2,431.99	0.39	0.25
Terraces	Ft	22,000	51,553	234	39,031	90	35,127.95	0.75	0.68
Tile Drains	Ft	200,300	134,316	67	152,086	70	106,460.79	1.13	0.79
Tree Planting	Ac	10	0	0	0	70	0.00	0.00	0.00
Wildlife Habitat Management	Ac	222	148	67	1,952	60	1,171.37	13.19	7.91
Woodland Improved Harvesting	Ac	200	0	0	0	65	0.00	0.00	0.00
Woodland Improvement	Ac	610	0	0	0	70	0.00	0.00	0.00
Woodland Pruning	Ac	50	0	0	0	70	0.00	0.00	0.00
TOTAL (WATERSHED)	Ac	12,038			$709.791	Av.$73	518,876.59		

TABLE 102
Technical Assistance Cost SCS

Assistance	Hours	Dollars
Professional	14,509	$159,345.47
Subprofessional	8,284	70,746.90
Total	22,793	230,092.37*
Planning time	6,099	44,736.44
Application time	4,400	33,677.28
Group application time	3,557	29,639.92
Cartographic		1,223.53
Soils Mechanics Lab		1,761.75
Travel and support		2,147.35
GRAND TOTAL		235,225.00

*Includes employee benefits and overhead.

Costs for land treatment thus total nearly $910,000 for the 12,000 acre Black Creek watershed. The analysis of this cost and its relationship to the Black Creek watershed, the Maumee Basin, and other agricultural watersheds is included in the next section.

5.1.1 Analysis of Costs

As previously stated, a total conservation approach to any watershed must involve more than a consideration of water quality. The initial planning for the Black Creek project listed 33 categories in which the costs could be incurred for specific conservation practices. These were outlined in Table A-10 of the initial work plan according to estimated costs per year. Table A-10 is reproduced here as Table 101.

The practices listed in Table 101 were described in detail in the work plan as follows:

5.1.1.1 CONSERVATION CROPPING SYSTEMS

Growing crops in combination with needed cultural and management measures. Cropping systems include rotations that contain grasses and legumes as well as rotations in which the desired benefits are achieved without the use of such crops.

5.1.1.2 CONTOUR FARMING

Farming sloping cultivated land in such a way that plowing preparing and planting, and cultivating are done on the contour. (This includes following established grades of terraces, diversions, or contour strips.)

5.1.1.3 CRITICAL AREA PLANTING

Stabilizing silt-producing and severely eroded areas by establishing vegetative cover. This includes woody plants, such as trees, shrubs or vines, and adapted grasses or legumes established by seeding or sodding to provide long-term ground cover. (Does not include tree planting mainly for the production of wood products.)

5.1.1.4 CROP RESIDUE MANAGEMENT

Using plant residues to protect cultivated fields during critical erosion periods.

5.1.1.5 DIVERSIONS

A channel with a supporting ridge on the lower side constructed across the slope.

5.1.1.6 FARMSTEAD AND FEEDLOT WINDBREAKS

A belt of trees or shrubs established next to a farmstead or feedlot.

5.1.1.7 FIELD BORDER PLANTING

A border or strip of perennial vegetation established at the edge of a field by planting or by converting from trees or crop production to herbaceous vegetation or shrubs.

5.1.1.8 FIELD WINDBREAKS

A strip or belt of trees or shrubs established to reduce wind erosion.

5.1.1.9 GRADE STABILIZATION STRUCTURE

A structure to stabilize the grade or to control head cutting in natural or artificial channels. (Does not include stream channel improvement, streambank protection, diversion, or structure for water control.)

5.1.1.10 GRASSED WATERWAYS

A natural or constructed waterway or outlet shaped or graded and established in vegetation suitable to safely dispose of runoff from a field, diversion, terrace or other structure.

5.1.1.11 HOLDING PONDS AND TANKS

A fabricated structure or one made by constructing a pit dam or embankment for temporary storage of animal or agricultural wastes, associated runoff and waste water.

5.1.1.12 LAND SMOOTHING

Removing irregularities on the land surface by use of special equipment.

5.1.1.13 LIVESTOCK EXCLUSION

Excluding livestock from an area where grazing is not wanted.

5.1.1.14 LIVESTOCK WATERING FACILITY

A trough or tank with needed devices for water control to provide drinking water for livestock.

5.1.1.15 MINIMUM TILLAGE

Limiting the number of cultural operations to only those that are properly timed and essential to produce a crop and prevent soil damage.

5.1.1.16 PASTURE AND HAYLAND MANAGEMENT

Proper treatment and use of pastureland or hayland.

5.1.1.17 PASTURE AND HAYLAND PLANTING

Establishing and re-establishing long-term stands of adapted species of perennial, biennial, or reseeding forage plants. (Includes pasture and hayland renovation; does not include grassed waterway or outlet on cropland.)

5.1.1.18 PONDS

A water impoundment made by constructing a dam across a water-course or a natural basin, or by excavating a pit or "dugout". (Such ponds do not include spring development or irrigation reservoirs.)

5.1.1.19 PROTECTION DURING DEVELOPMENT

Treatment based on a plan to control erosion and sediment during development for residential, commercial-industrial, community services, transportation routes or utility uses.

5.1.1.20 RECREATION AREA IMPROVEMENT

Establishing grasses, legumes, vines, shrubs, trees, or other plants or managing woody plants to improve an area for recreation.

5.1.1.21 SEDIMENT CONTROL BASINS

A barrier or dam constructed across a waterway or at other suitable locations to form a silt or sediment basin.

5.1.1.22 STREAM CHANNEL STABILIZATION

Stabilizing the channel of a stream with suitable structures.

5.1.1.23 STREAMBANK PROTECTION

Stabilizing and protecting banks of streams or excavated channels against scour and erosion by the use of vegetative or structural means.

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5.1.1.24 STRIPCROPPING

Growing crops in a systematic arrangement of strips or bands on the contour to reduce erosion.

5.1.1.25 SURFACE DRAINS

A graded channel for collecting excess water within a field. This does not include grassed waterway or outlet.

5.1.1.26 TERRACE, GRADIENT

An earth embankment or a ridge and channel constructed across the slope at a suitable opening and an acceptable grade to reduce erosion damage and pollution by intercepting surface runoff and conducting it to a stable outlet.

5.1.1.27 TERRACE, PARALLEL

An earth embankment or a ridge channel constructed in parallel across the slope at a suitable spacing and acceptable grade to reduce erosion and pollution and provide a more farmable terrace system.

5.1.1.28 TILE DRAINS

A conduit, such as tile, pipe or tubing, installed beneath ground surface and which collects and/or conveys drainage water. The project goal was approximately 200,300 lineal feet needed only for erosion and sediment control of surface drains and grassed waterways.

5.1.1.29 TREE PLANTING

Planting tree seedlings or cuttings.

5.1.1.30 WILDLIFE HABITAT MANAGEMENT

Retaining, creating, or managing wildlife habitat for both upland and wetland.

5.1.1.31 WOODLAND IMPROVED HARVESTING

Systematically removing some of the merchantable trees from an immature stand to improve the conditions for forest growth.

5.1.1.32 WOODLAND IMPROVEMENT

Improving woodland by removing unmerchantable or unwanted trees, shrubs or vines.

5.1.1.33 WOODLAND PRUNING

Removing all or parts of selected branches from trees.

The Black Creek project was an experimental project. It was begun as an attempt to evaluate several practices. Of an initial list of 32 practices, previously described, 12 have been selected as best management practices. These are listed in Table 103, along with total unit cost of installation. These costs are based on the actual contracts awarded in Black Creek.

TABLE 103
Cost of BMP Installation

Practice	Unit	Cost
Field Border	Mile	1,584
Holding Tanks	Each	5,600
Sediment Basins	Each	5,000
Contour Farming	(1)	(1)
Critical Area Planting	Acre	400
Crop Residue Management	(2)	(2)
Grassed Waterways	Acre	1,200
Livestock Exclusion (fencing)	Foot	0.50
Reduced Tillage	(3)	(3)
Pasture Renovation and Planting	Acre	100
Terraces	Foot of terrace (with tile)	1.75

(1) very little application in Black Creek Area or Maumee Basin.
(2) can be applied by management techniques without additional cost.
(3) considered only on soils where reduced tillage should not result in significant yield penalties.

At the completion of the project new estimates were made of the amounts of each of these practices which should have been installed to meet water quality goals.

It should be emphasized that these amounts do not represent totals actually installed, but rather the amounts that should have been installed if the designers of the project could have known the results from the Black Creek project when it began. In some cases the amount is greater than the amount actually applied. These amounts as estimated for Black Creek watershed are set out in Table 104.

These amounts can be multiplied by the cost of land treatment practices to derive estimated costs for the project if all recommended practices had been applied and if no practice were applied that were not needed. These results are presented in Table 105.

Amounts of tnese practices can be projected to the total basin on to the basis of the similarities between the Black Creek Watershed and the basin. This projection is made in the following discussion, not as a plan for the Maumee, but as an example of how Black Creek cost figures can be

TABLE 104
Estimated BMPs Needed at Beginning of Black Creek Project

Practice	Amount Needed
Field Borders	40 miles
Holding Tanks	10
Sediment Basins	6
Critical Area Planting	10 acres
Grassed Waterways	68 acres
Livestock Exclusion (fencing)	15,000 feet
Pasture Renovation and Planting	400 acres
Terraces	44,000 feet

TABLE 105
Projected Costs of Ideal Black Creek Land Treatment

Practice	Cost
Field Border	63,360
Holding Tanks	56,000
Sediment Basins	30,000
Critical Area Planting	4,000
Grassed Waterways	81,600
Livestock Exclusion (fencing)	7,500
Pasture Renovation	4,000
Terraces	77,000
Total	323,460

applied. The following rationale was used.

Field Borders: In Black Creek, a field border is defined as a 16-foot strip of vegetation (usually sod) placed along a water course in cropland. It is estimated, based on figures supplied by the Soil Conservation Service in Ohio, that 13,800 miles of such stream bank exists in the basin. The total amount of field border needed would thus be 13,800 miles times two or 27,000 miles. This amount multiplied by a unit cost of 1584 yields an estimated basin cost of $42.7 million.

Holding Tanks: In Black Creek, about 1/5 to 1/4 of the livestock operations needed holding tanks to improve water quality. If the same ratio holds in the Maumee Basin, the amount needed would be 800 to 1000.

Sediment Basin: There were six sites in Black Creek for sediment basins. Multiplication this by the ratio of Black Creek area to basin area would result in 2100 sites. Since the erosive area of the watershed is only 2/3 that of the basin, the number of sites could be as low as 1400.

Critical Area Planting: It was estimated that 10 acres of critical area planting were needed in the Black Creek area. Projecting this amount to the total basin by the previously described method results in an estimate of 2500 to 3500 acres for the basin.

Grassed Waters: Applying the same types of estimates to grassed waterways results in the following estimates: 16,000 - 24,000.

Livestock Exclusion: Applying these factors plus a correction based on the fact that livestock is more common in Black Creek than in the Basin by about a 3/2 ratio, results in an estimate of 500 miles of fencing needed. This is higher by a factor of 10 than the amount estimated in other studies, which may indicate that extensive fencing has already been done.

Pasture Planting: In Black Creek, it was determined that about 4/5 of the existing pasture needed replacement or renovation. Applying this to the 125,000 acres of pasture results in an estimated 100,000 acres.

Terraces: Applying the standard corrections to the 44,000 feet of terrace needed in Black Creek results in 12,000,000 to 15,000,000 feet needed in the Basin.

These estimates, multiplied by the Black Creek costs give a cost estimate for the basin. This is shown in Table 106.

TABLE 106
Estimated Costs - Maumee Basin

Practice	Cost
Field Borders	43,700,000
Holding Tanks	4,480,000-5,600,000
Sediment Basins	7,000,000-10,500,000
Critical Area Planting	1,000,000-1,400,000
Grassed Waterway	19,200,000-28,000,000
Livestock Exclusion	1,300,000
Pasture Planting	10,000,000
Terraces	21,000,000-26,250,000
Total	107,480,000-126,250,000

In the preceding analysis, no costs are assigned for systems related to conservation tillage, although crop residue management and conservation tillage are both considered to be important water quality management practices in the Black Creek Watershed and the Maumee Basin. In fact, it is estimated that most of the approximately 4,600 acres of land in the Black Creek Watershed which has an erosion problem and which is utilized for row crop production and most of the 1.4 million acres in the Maumee Basin which is in crop production and which is subject to erosion, would benefit from a water quality standpoint from conservation tillage practices. However, it is further believed that careful selection of the areas where this is undertaken and a willingness to phase-in new tillage systems can result in achieving this practice at virtually no cost.

Capital costs associated with changes of tillage -- such as an estimate of the cost of chisel plows or no-till planters that would be needed -- have been included in some estimates of cost of conservation application in the Maumee Basin. However, if the purchase of this equipment is allowed to be phased-in so that it can be obtained as a part of normal equipment replacement system of individual farms, the costs are greatly reduced. Landowners regularly replace equipment to maintain complex modern farms. The cost of electing to purchase a new chisel plow rather than a new moldboard plow is not a significant one.

Other costs associated with changes in tillage relate to normal operating costs and any yield reduction that might be associated with the new tillage.

In the Maumee Basin and Black Creek it can be expected that certain operational costs -- those associated with depreciation of equipment, fuel for tillage operations and labor in tillage operations will be reduced by reducing the amount of tillage done. On the other hand, certain costs, largely those associated with chemical weed or pest control, will be higher in reduced tillage systems. As a rule of thumb, for both corn and soybeans, it can be assumed that the savings on one hand and the increased chemical costs on the other will likely balance, leaving the impact on yield as the cost most associated with conservation tillage.

In the total basin, a relatively small amount of the land, about 170,000 acres, can be considered suitable for greatly reduced tillage or no-till systems. This represents cropland that can be expected to have an erosion problem, but which does not have a wetness hazard. About 1.2 million acres of the basin has both an erosion hazard and a wetness hazard. Tillage systems which leave large quantities of surface residue will reduce drying of these soils in the spring and will slow warming of the soil. During years with wet and cool springs, significant yield reductions can be anticipated on this type of land.

In the Black Creek project, conservation tillage was defined as a tillage system which included one primary tillage operation (spring or fall), one secondary tillage operation (spring, no more than one field cultivation, and no moldboard plowing. This system reduced erosion and was, in some cases, superior to conventional tillage.

It is believed that this type of tillage system could be extended into most of the erosive areas of the Maumee Basin without danger of significant yield reduction, particularly in corn and soybean rotations. In any long-term attempt to introduce conservation tillage, however, the option to periodically moldboard plow to aid in weed or disease control should be given landowners.

5.1.2 Arriving at BMP's

The best management practices recommended for water quality improvement in the preceding discussion were selected in relationship to water quality. Water quality is not, however, the only goal that needs to be considered in the planning of the best land use within an agricultural watershed.

Conservation practices in the Black Creek project have been arbitrarily categorized in four separate classification:

1. Those which benefit water quality
2. Those which protect the soil resource
3. Those which enhance production capability
4. Those which accomplish other conservation purposes

The wise use of the land resource requires that all of these objectives be considered when planning is undertaken. In fact, a watershed which has been properly managed will have elements of each of these categories and an ideally managed watershed can be considered one in which all of the four classifications is maximized. Unfortunately, in the real watershed which must be considered, these classifications can be conflicting. It may not, for example, be possible to have maximum crop production and maximum water quality at the same time. It may also not be possible to have maximum water quality, as defined by concentrations of nutrients, and maximum wildlife production in the same watershed at the same time.

For example, as has been previously discussed, sediment may be reduced by placing large quantities of stone on eroding channel banks and degrading channel bottoms. This, on the other hand, may interfere with fish communities through the reduction of habitat diversity.

Conversely, some practices may serve more than one of the four classifications. A practice may, for example, serve to both preserve the soil resource and improve water quality. A practice such as converting erosive crop land into a wildlife habitat might serve the purpose of soil protection, improvement of water quality, and the additional conservation purpose of wildlife protection.

While this is very useful from an environmental viewpoint, it is much less simple from an administrative viewpoint. Precisely, if a practice can be said to have both a water quality benefit and a soil protection benefit, and some agency is funding water quality improvement programs only, does that practice meet the requirement of water quality improvement. Similarly, if a project improves water quality, but has an adverse effect on wildlife, and these two aspects are being regulated by different agencies, how is a conflict to be resolved? In order to obtain some insight into these kinds of administrative questions, all of the practices in the Black Creek project were evaluated on the basis of each of the four classifications. These results are included in Table 107.

This analysis was then utilized to assign Black Creek actual land treatment costs to each of the four categories. The results are included in Figure 33.

DISCUSSION

As can be seen from Table 107 and Figure 33, a large share of funds spent in the Black Creek demonstration project went for practices that were not directly related to water quality. On the other hand, according to the

TABLE 107
Evaluation of Practices Applied in Black Creek Watershed

Practice	Water Quality	Soil Protection	Crop Production	Other Conservation Uses
Conservation Cropping System	2	1	3	2
Contour Farming	1	1	3	3
Critical Area Planting	1	1	3	2
Crop Residue Management	1	1	2	2
Diversions	2	1	3	4
Farmstead Windbreaks	3	2	4	1
Field Border	1	2	4	2
Field Windbreaks	2	1	3	2
Grade Stabilization Structures (1)	2	1	3	4
(a) aluminum toewall overfall str.				
(b) surface water inlet pipes				
(c) tile outlet protection pipes				
Grassed Waterway	1	1	3	3
Holding Pond and Tanks (Animal Waste)	1	3	2	4
Land Smoothing	4	3	1	4
Livestock Exclusion	1	1	4	2
Livestock Watering Facility	2	2	4	3
Minimum Tillage	1	1	3	2
Pasture Management	1	1	2	3
Pasture Planting	1	1	2	2
Pond	2	2	4	1
Protection During Development	2	1	4	2
Recreation Area Improvement	2	2	4	1
Sediment Control Basins	1	3	4	2
Stream Channel Stabilization (2)	2	1	3	3
Streambank Protection (3)	3	2	1	2
Stripcropping	2	1	2	2
Surface Drains	3	3	1	4
PTO Terraces	1	1	2	2
Tile Drains (4)	3	2	1	3
(a) 4 inch				
(b) 5 inch				
(c) 6 inch				
(d) 8 inch				
(e) 10 inch				
(f) 12 inch				
(g) 14 inch				
(h) 15 inch				
Tree Planting	2	2	4	1
Wildlife Habitat Management	3	3	4	1
Woodland Improved Harvesting	3	3	2	1
Woodland Improvement	3	2	2	1
Woodland Pruning	3	2	2	1

(footnotes Next Page)

Direct Benefit

1 -- Primary Benefit 2 -- Secondary Benefit 3 -- Very little, if any Benefit 4 -- No Benefit

(1) Includes both over-fall structures and surface inlet pipes. If we only considered over-fall structures we might justify primary benefit (1) to water quality, however, surface pipes are definately not primary for water quality.

(2) Stream channel stabilization includes all use of rip-rap stone for stabilizing channel banks and bottoms. Rock drop structures are included here. The practice should be limited to critical eroding areas only.

(3) Streambank protection involved using mechanical hoes to pull channel banks back to stable slope and vegetating with grass mixtures. In some case material was removed from the channel bottom to improve drainage capacity of the channel.

(4) Tile drains are primarily for removing subsurface water to improve crop production by reducing the wetness problems however, tile drains are a necessary part of some water quality BMP's such as grass waterways and terraces.

* Total cost for W/Q BMP's Applied = 211,383.49.
** Total District Payment for water quality BMP applied = 152,229.88.

Total BMP cost per acre in watershed (12,000 Ac) over five years = 17.61 or 3.52/yr.

District Payment for BMP per acre in watershed over 5 years = 12.68

DISCUSSION

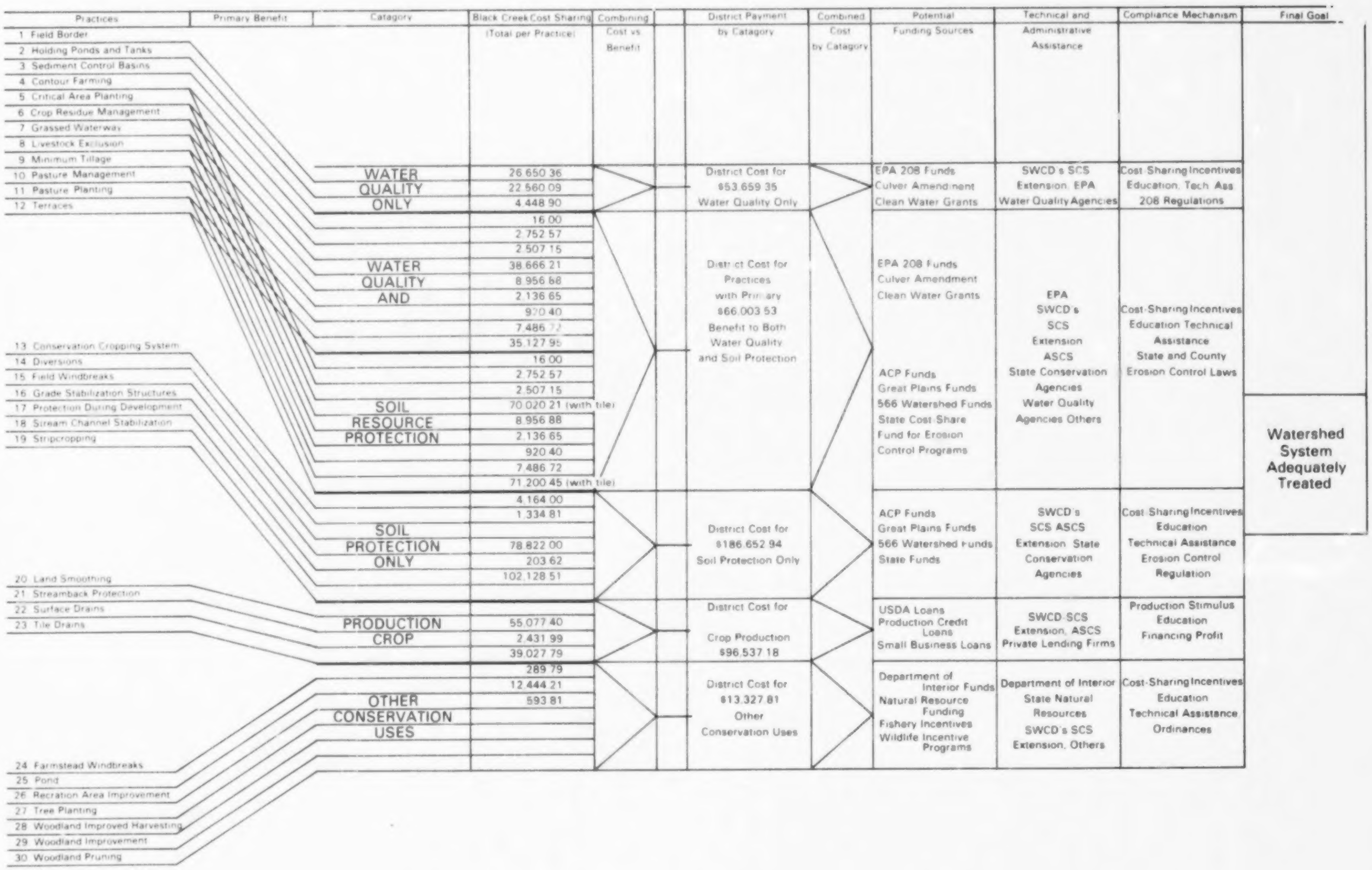
Practices
Primary Benefit
Catagory
Black Creek Cost Sharing (Total per Practice)
Combining Cost vs Benefit
District Payment by Catagory
Combined Cost by Catagory
Potential Funding Sources
Technical and Administrative Assistance
Compliance Mechanism
Final Goal
1 Field Border
2 Holding Ponds and Tanks
3 Sediment Control Basins
4 Contour Farming
5 Critical Area Planting
6 Crop Residue Management
7 Grassed Waterway
8 Livestock Exclusion
9 Minimum Tillage
10 Pasture Management
11 Pasture Planting
12 Terraces
13 Conservation Cropping System
14 Diversions
15 Field Windbreaks
16 Grade Stabilization Structures
17 Protection During Development
18 Stream Channel Stabilization
19 Stripcropping
20 Land Smoothing
21 Streamback Protection
22 Surface Drains
23 Tile Drains
24 Farmstead Windbreaks
25 Pond
26 Recration Area Improvement
27 Tree Planting
28 Woodland Improved Harvesting
29 Woodland Improvement
30 Woodland Pruning
WATER QUALITY ONLY
WATER QUALITY AND
SOIL RESOURCE PROTECTION
SOIL PROTECTION ONLY
PRODUCTION CROP
OTHER CONSERVATION USES
26 650 36
22 560 09
4 448 90
16 00
2 752 57
2 507 15
38 666 21
8 956 68
2 136 65
920 40
7 486 72
35 127 95
16 00
2 752 57
2 507 15
70 020 21 (with tile)
8 956 88
2 136 65
920 40
7 486 72
71 200 45 (with tile)
4 164 00
1 334 81
78 822 00
203 62
102 128 51
55 077 40
2 431 99
39 027 79
289 79
12 444 21
593 81
District Cost for $53 659 35 Water Quality Only
District Cost for Practices with Primary $66 003 53 Benefit to Both Water Quality and Soil Protection
District Cost for $186 652 94 Soil Protection Only
District Cost for Crop Production $96 537 18
District Cost for $13 327 81 Other Conservation Uses
EPA 208 Funds
Culver Amendment
Clean Water Grants
EPA 208 Funds
Culver Amendment
Clean Water Grants
ACP Funds
Great Plains Funds
566 Watershed Funds
State Cost Share
Fund for Erosion
Control Programs
ACP Funds
Great Plains Funds
566 Watershed Funds
State Funds
USDA Loans
Production Credit Loans
Small Business Loans
Department of Interior Funds
Natural Resource Funding
Fishery Incentives
Wildlife Incentive Programs
SWCD's SCS
Extension, EPA
Water Quality Agencies
EPA
SWCD's
SCS
Extension
ASCS
State Conservation Agencies
Water Quality Agencies Others
SWCD's
SCS ASCS
Extension, State Conservation Agencies
SWCD SCS
Extension, ASCS
Private Lending Firms
Department of Interior
State Natural Resources
SWCD's SCS
Extension, Others
Cost Sharing Incentives
Education, Tech Ass
208 Regulations
Cost Sharing Incentives
Education Technical Assistance
State and County
Erosion Control Laws
Cost Sharing Incentives
Education
Technical Assistance
Erosion Control Regulation
Production Stimulus
Education
Financing Profit
Cost Sharing Incentives
Education
Technical Assistance
Ordinances
Watershed System Adequately Treated

Figure 33. Assignment of Costs to Categories

previous analysis, only slightly more than $320,000 is now thought to have been necessary to have achieved water quality objectives through land treatment. The primary reason for the substantial differences between these two cost figures is the research and demonstration nature of the project.

One weakness of all of the above analyses from the standpoint of water quality is the inability at this time to precisely relate costs of land treatment to levels of water quality. It is not possible, for example, to state that the $212,000 spent on water quality practices in the Black Creek Watershed improved the quality of water in Black Creek by some percentage. It is also not possible to project what spending $323,000 on water quality practices, would have accomplished; and it is not possible to make an estimate of how much the Maumee River or Lake Erie would benefit by carrying out all of the recommended practices.

The ANSWERS model, which is discussed in detail elsewhere in this report, provides a mechanism by which these benefit and costs can be predicted for small watersheds, and through the judicious selection of sample watersheds (as the Black Creek area was selected to represent the Maumee Basin) to much larger areas. The ANSWERS model will, in its final form, be capable of predicting improvements in water quality accomplished by specific land treatment practices. By a technique similar to that with which Black Creek costs were projected to the entire basin, water quality improvements can be projected from carefully modelled sample watersheds.

5.1.3 Engineering Observations

Three engineering practices were investigated in the Black Creek Watershed which were previously not common practices within the Soil Conservation Service in Indiana. Two of these practices involved the use of stone for channel protection. The third involved the application of terraces in areas where terraces had not been normally be applied in the past.

Terraces applied in the Black Creek project were of the parallel type with tile outlets, PTO. A typical arrangement is shown in Figure 34.

These terraces, with tile outlets, differ from graded terraces in that they are laid out parallel to each other across the water course graded slope. They use tile to carry away the water. They serve the dual purpose of reducing slope length (and thereby erosion) and temporary retention of surface water which in turn allows some sediment and attached pollutants to settle out of the water before it enters the subsurface drain.

PTO terraces as used in Black Creek are, in general, shorter than conventional PTO terraces. They are not necessarily constructed perpendicular to the slope but are perpendicular to the minor water courses. A series of terraces are installed, designed according to SCS standards so as to prevent overtopping during a 10 year frequency storm event.

The number and size of terraces needed is dependent on the size of the drainage area being treated. Outflow from the terrace is accomplished by a riser pipe, upstream from the terrace. An orifice plate determines the rate at which water will be discharged from the ponding behind the terrace into the subsurface outlet. The size of the orifice determines maximum flow. Outlet tile need be designed only large enough to accomodate the

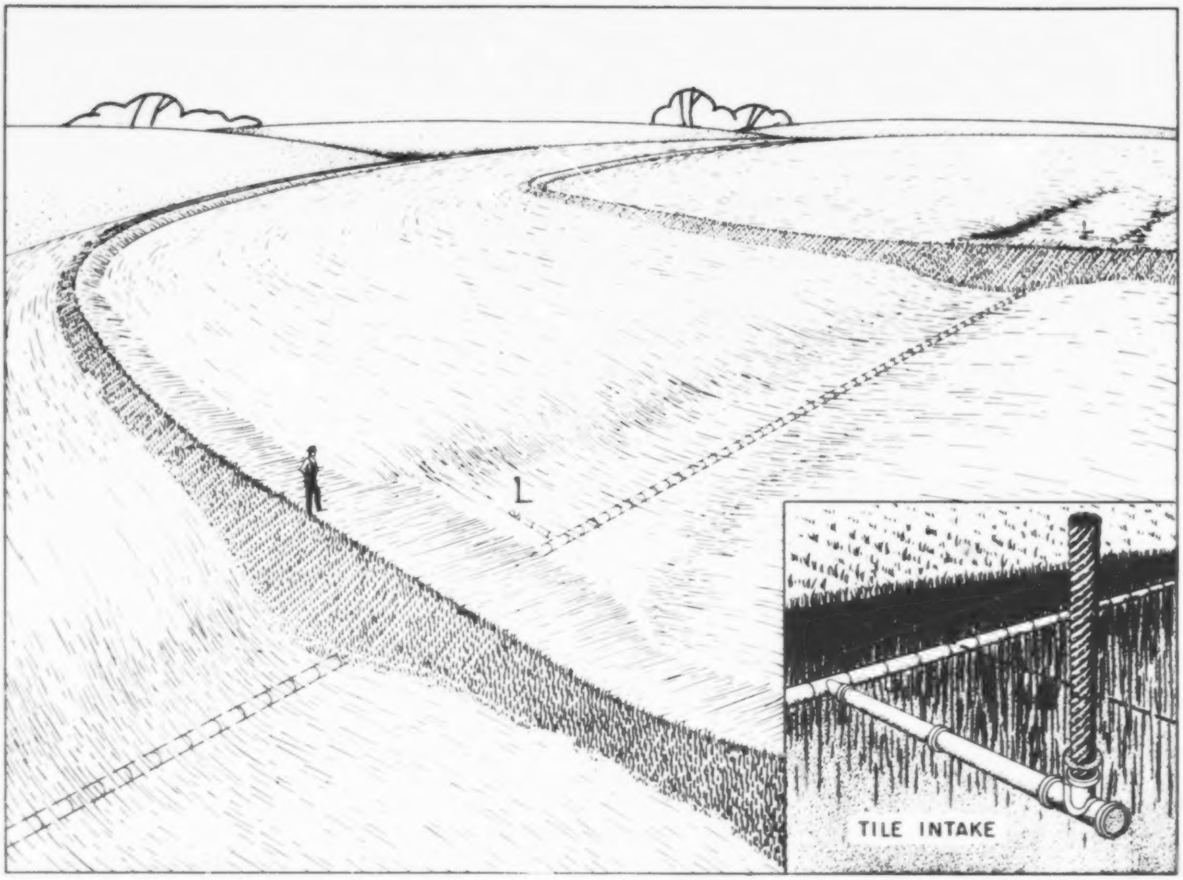

Figure 34. Typical PTO Terrace Arrangement

flow through this metered orifice. Orifice size and tile size are determined on the basis of that necessary to allow discharge of all of the ponded runoff from the design storm in a 24 hour period.

Longer versions of the PTO terrace serve the same purpose as do conventional grass-back or broad-based parallel terraces, perpendicular to the field slope. In some cases, terraces were installed in the Black Creek area specifically for their sediment control functions. These terraces generally involve smaller areas of steeper side slopes and function primarily as temporary sediment basins.

Rock was used in the Black Creek project, both as an attempt to remove velocity from areas of rapid fall in stream channels and in unstable soil, to prevent undermining of the channel at the seepage line.

Details of one of these structures, intended for protection of unstable channels are included in Figure 35. In Black Creek, stone for protection was established to elevations above the seepage line of one, two and three feet for experimental purposes. Cost of this installation was roughly $3 per lineal foot for the one foot series, $6 for the two foot series, and $9 for the three foot series. Observations have indicated that all three types of installations are equally satisfactory in reducing channel instability. It is therefore as successful to use the one foot elevation as it is the three foot elevation resulting in a potential practical saving of $6 per linear foot in areas suited to the practice application.

Structures called rock-drop structures were included in the project at areas where rapid change in channel elevation produced erosion or bank stability problems through the high velocity of the water.

5.2 SOURCES OF SEDIMENT AND RELATED POLLUTANTS

5.2.1 Comparison of Subwatersheds

5.2.1.1 INTRODUCTION

The Maumee River is usually a gently flowing river and even in flood periods the velocities are relatively low because the gradient is not steep. However, the waters in the Maumee River never appear clear because of its suspended sediment load. For a 10-year period of record, 1961-71, the sediment rate from the Maumee River into Lake Erie averaged about 500 kg/ha (a kilogram per hectare is roughly equivalent to a pound per acre) annually (1,2). However, sediment yields even of this rather low order of magnitude may be important in lowering the water quality in Lake Erie because they are composed mostly of colloidal-sized particles. For a small volume, the sediments can carry a high nutrient load, particularly phosphorus. Unknown at this time, however, is the contribution which phosphorus attached to sediments actually makes to the eutrophication rate of Lake Erie. It is implicitly assumed in this study that some of the attached phosphorus becomes available to the eutrophication process occurring in Lake Erie.

This section reports on the sediment and nutrient yields from the Black Creek Watershed into the Maumee River. In particular, it compares the data collected from two major drainage areas within the watershed. However, the reported results are based only on a two-year period of record, 1975 and 1976, which is a rather short hydrological period on which to make definite conclusions. As a consequence, the conclusions reached are subject to further modification with succeeding years of record.

5.2.1.2 STUDY AREA AND METHODS

The Black Creek Watershed was chosen as being fairly representative of the soils and agricultural practices of the Maumee Basin although it is only 4950 ha in size compared to 1,711,500 ha for the Maumee Basin. An outline map of the experimental watershed together with instrumentation and sampling sites is shown in Figure 36.

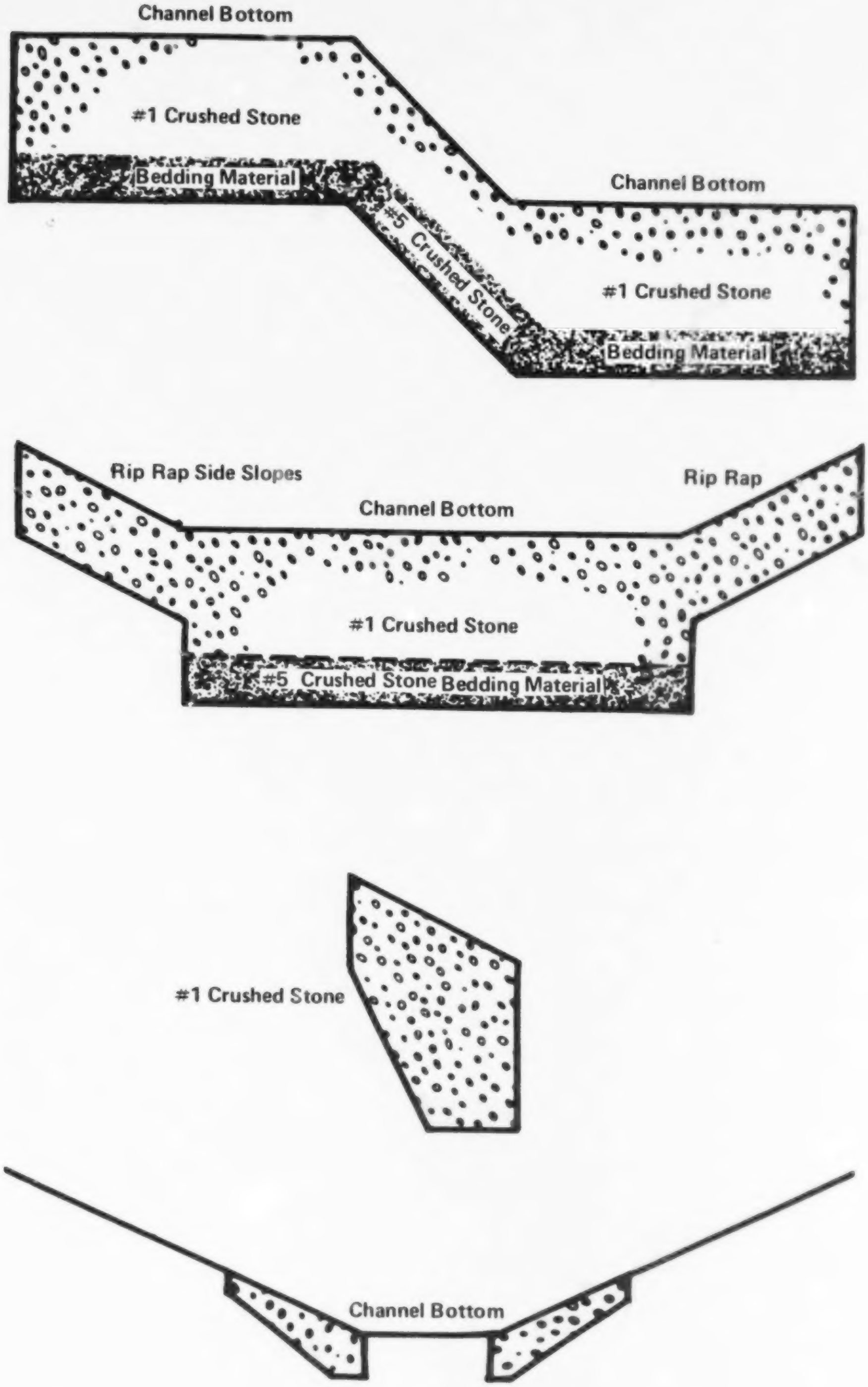
Channel Bottom
#1 Crushed Stone
Bedding Material
#5 Crushed Stone
Channel Bottom
#1 Crushed Stone
Bedding Material
Rip Rap Side Slopes
Rip Rap
Channel Bottom
#1 Crushed Stone
#5 Crushed Stone
Bedding Material
#1 Crushed Stone
Channel Bottom

Figure 35. Details of Channel Protecting Structure

DISCUSSION

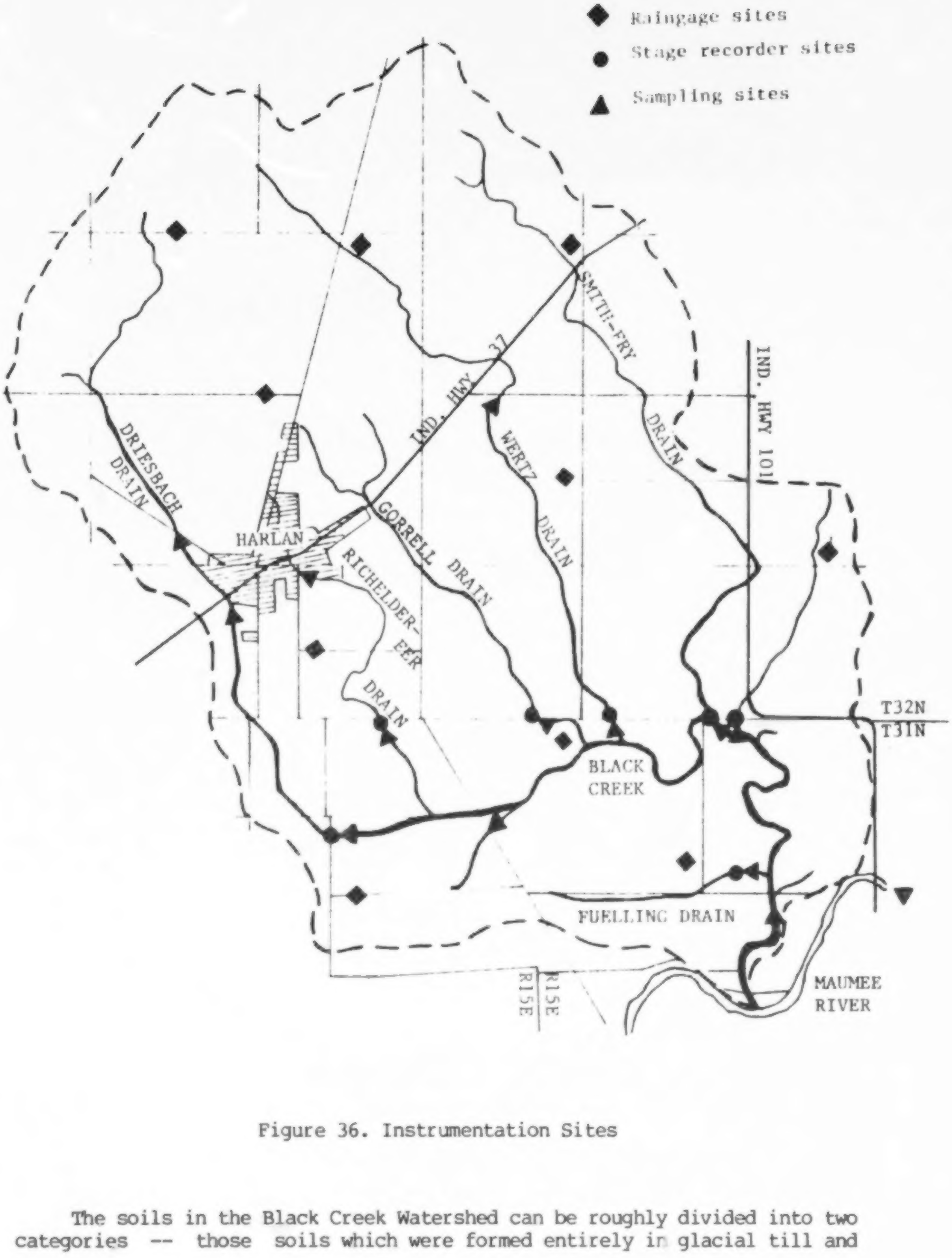
◆ Raingage sites
● Stage recorder sites
▲ Sampling sites
IND. HWY 37
SMITH-FRY
DRAIN
IND. HWY 101
DRIESBACH
DRAIN
WERTZ
DRAIN
HARLAN
GORRELL DRAIN
RICHELDER-EER
DRAIN
T32N
T31N
BLACK
CREEK
FUELLING DRAIN
R15E
R15E
MAUMEE
RIVER

Figure 36. Instrumentation Sites

The soils in the Black Creek Watershed can be roughly divided into two categories -- those soils which were formed entirely in glacial till and

DISCUSSION

those soils which were also influenced at various stages in their formation by shallow water cover or by wave action. These soil categories are subsequently referred to as glacial till soils and lake plain and beach ridge soils, respectively. Indiana Highway 37 as shown in Figure 36 divides these soils fairly well with the glacial till soils to the north and the lake plain and beach ridge soils to the south. The glacial till soils are gently rolling while the lake plain soils are nearly level.

Two of the major drainage areas which empty into Black Creek, that of the Dreisbach Drain and Smith-Fry Drain, were studied intensively. The Dreisbach Drain is located along the western boundary of the watershed and the Smith-Fry Drain is located along the eastern boundary. Their drainage areas, of comparable size, represent the greatest contrast in soils and land use within the watershed. The drainage area of the Dreisbach Drain contains 74 percent rolling and 26 percent nearly level topography while that of the Smith-Fry Drain contains only 29 percent rolling and 71 percent nearly level topography. The land use is also quite different with 35 percent of the drainage area of the Dreisbach Drain in row crops as compared to 63 percent for the drainage area of the Smith-Fry Drain. The drainage area of the Dreisbach Drain also contains the town of Harlan which has an effect on water quality in that stream. Characteristics of these two drainage areas as well as those for the Black Creek Watershed are given in Table 108. Note that characteristics of the total watershed are very similar to those for the drainage area for the Smith-Fry Drain.

TABLE 108
Characteristics of the Areas Studied

Characteristics	Black Creek Watershed	Smith-Fry Drain	Dreisbach Drain
Drainage area:	4950 ha	942 ha	714 ha
Soil groups:			
Lake plain & beach ridge	64%	71%	26%
Glacial till	36%	29%	74%
Land use:			
Row crops	58%	63%	35%
Small grain & pasture	31%	26%	48%
Woods	6%	8%	5%
Urban, roads, etc.	5%	3%	12%
Homes:		28	143

Sediment and nutrient yields from the Black Creek Watershed and the drainage areas for the Dreisbach Drain and Smith-Fry Drain were determined by integrating sediment and nutrient concentrations with flow rates. Stage-discharge relationships were developed for the outlets of these study areas to give flow rates. Water stages were recorded continuously at these locations with a pressure-type stage recorder (Model 12 Flow Recorder, Foxboro). (Product descriptions and manufacturers are given for reader information and should not be construed as endorsements.)

Water samples for determining the concentrations of sediment and nutrients were collected either manually or with automated samplers. Grab samples were collected each week and also during storm events. The automated samplers were triggered at a set minimum stage and then continued to operate automatically until the sample storage was exhausted or the stage fell below the set minimum stage. The water samples were normally collected and the automated sampler reset before the sample storage was exceeded.

Three automated pumping samplers (PS-69, U.S. Interagency Sedimentation Project) were installed at the junctions of the Dreisbach and Smith-Fry Drains with Black Creek and on the main stem of Black Creek near its entrance into the Maumee River. Each sampler was capable of automatically collecting 72 samples of 500 ml each at a chosen time interval.

After the samples were collected, they were frozen within 24 hours. Before analysis, the samples were thawed and one-half of the sample filtered. Suspended sediment was determined by passing 200 ml of runoff through a tared membrane filter (0.40 pore diameter, Nucleopore) and then weighing the collected solids after oven drying at 105 degrees C for 24 hours.

The nutrients analyzed were nitrogen and phosphorus and their constituent forms. Ammonium and nitrate in the filtrate were determined by the method of Bremner and Kenney (3). Total nitrogen in the filtered and unfiltered samples were determined by the method of Nelson and Sommers (4). Soluble inorganic phosphorus in the filtrate was analyzed by procedures outlined by Murphy and Riley (5). And total phosphorus was determined by the method described by Sommers and Nelson (6). A detailed description of the analyses procedures is given in the Section 0.0.2.1 of this volume.

5.2.1.3 RESULTS AND CONCLUSIONS

The results and conclusions associated with sediment and nutrient yields are based on two years of record -- 1975 and 1976. Precipitation for 1975 was about 20 percent over normal, but for 1976 it was about 20 percent less than normal. Fortunately these two years represent as wide a variation in precipitation amounts and patterns as will likely occur over a lengthy period of record.

For better comprehension of the data, the reader should remember that 1975 was a wet year and 1976 was a relatively dry year. Also the reader should remember that the drainage area for the Dreisbach Drain was more rolling and less intensively farmed than the drainage area for the Smith-Fry Drain. Also as an aid to the reader, conclusions are reported under each subheading while the information upon which they are based is still apparent to the reader.

5.2.1.3.1 Values of Important Parameters

The rainfall, runoff, sediment yields and total nitrogen and phosphorus yields for the Black Creek Watershed and the drainage areas of the Dreisbach Drain and Smith-Fry Drain are given in Table 109.

Note under the column for Black Creek Watershed that a 40 percent reduction in rainfall from 1975 to 1976 resulted in 60 percent reduction in runoff, a greater than fourfold reduction in sediment yield, a greater than

TABLE 109
Rainfall and Runoff Amounts and Yields of Sediment and Nutrients

Parameter	Year	Black Creek Watershed	Smith-Fry Drain	Dreisbach Drain
Rainfall	1975	112 cm	112 cm	112 cm
	1976	70 cm	70 cm	70 cm
Runoff	1975	27.5 cm	29.1 cm	26.0 cm
	1976	11.2 cm	12.4 cm	10.1 cm
Sediment	1975	2370 kg/ha	2130 kg/ha	3740 kg/ha
	1976	530 kg/ha	640 kg/ha	380 kg/ha
Total N	1975	48.7 kg/ha	53.2 kg/ha	44.1 kg/ha
	1976	8.6 kg/ha	10.3 kg/ha	6.6 kg/ha
Total P	1975	5.2 kg/ha	5.4 kg/ha	5.0 kg/ha
	1976	1.1 kg/ha	1.1 kg/ha	1.0 kg/ha

fivefold reduction in total nitrogen discharged, and about a fivefold reduction in total phosphorus discharged from the watershed. These data clearly demonstrate the adverse effects of excess rainfall.

Conclusion: Amounts of runoff, sediment, and nutrients discharged from a small watershed are greatly affected by rainfall. Reductions in rainfall give a greater percentage reduction in runoff which in turn gives a still greater percentage reduction in sediment and nutrient transport.

The runoff and sediment yield data for the drainage areas of the Smith-Fry Drain and the Dreisbach Drain present an interesting comparison.

The runoff from the drainage area for the Smith-Fry Drain was greater than that for the Dreisbach Drain in both 1975 and 1976. Although the drainage area for the Smith-Fry Drain was more level than the drainage area for the Dreisbach Drain, it also had better subsurface drainage and base flow also seemed to be sustained for longer periods of times from interflow through the ditch banks.

In 1975, the year with above normal rainfall, the sediment yield at the outlet of the Dreisbach Drain was about twice that at the outlet of the Smith-Fry Drain. However, in 1976, the reverse was true. Although all values were much lower, the sediment yield at the outlet of the Smith-Fry Drain was about twice that at the outlet of the Dreisbach Drain. The better land use in the drainage area of the Dreisbach Drain was apparently sufficient to retard runoff and subsequent erosion more than in the drainage area of the Smith-Fry Drain with its more intensive land use. However, when rainfall was excessive, as in 1975, greater runoff and subsequent erosion occurred on the drainage area of the Dreisbach Drain than on the drainage area of the Smith-Fry Drain because of steeper slopes on the drainage area of the Dreisbach Drain.

Conclusion: During years with above average rainfall, land slope is clearly the dominant factor affecting sediment yields. However, with below average rainfall, the effect of land use on sediment yields becomes relatively more important. This reflects the natural sequence of rainfall-runoff events because rainfall must first meet the storage capabilities of the soil and land surface before runoff begins.

5.2.1.3.2 Nutrient Transport

The total nutrient yields for 1975 and 1976 from the Black Creek Watershed and the drainage areas of the Smith-Fry and Dreisbach Drains were given in Table 109. Their constitutive forms in kg/ha are shown in Table 110.

TABLE 110
Nutrient Transport (kg/ha)

Component	Smith-Fry 1975	Smith-Fry 1976	Dreisbach 1975	Dreisbach 1976
Soluble inorganic P	0.14	0.06	0.34	0.18
Soluble organic P	0.10	0.03	0.12	0.04
Sediment P	5.2	0.98	4.5	0.73
Ammonium N	1.5	0.60	1.8	0.85
Nitrate N	19	5.5	12	2.4
Soluble organic N	1.7	0.31	2.3	0.53
Sediment N	31	3.9	28	2.8

All of the forms of nitrogen and phosphorus transported greatly decreased from 1975 to 1976 due primarily to decreased runoff. The amounts transported from one drainage area are roughly similar to the other except for soluble inorganic phosphorus and perhaps nitrate nitrogen.

The larger amounts of soluble inorganic phosphorus from the drainage area of the Dreisbach Drain were caused by the larger number of houses discharging domestic sewage into the Dreisbach Drain as compared to the Smith-Fry Drain. On the other hand, larger amounts of nitrate-N on a area basis were being discharged from the Smith-Fry Drain in comparison to the Dreisbach Drain very likely because of more extensive subsurface drainage and row crop farming in the drainage area of the Smith-Fry Drain.

Percentages of nitrogen and phosphorus forms which were transported past the outlets of the two drains are given in Tables 111 and 112.

Of interest in Table 111 is the shifting which takes place between the various nitrogen forms from 1975 to 1976. Sediment nitrogen was high in 1975 because excess rainfall caused more runoff during that year. In 1976, the relative dry year, ammonium and nitrate-N constituted a greater percentage of the total nitrogen transported than in 1975.

With regard to phosphorus transport, most of that which was transported was sediment-bound, as shown in Table 112.

Conclusion: With average or above average rainfall amounts, more than 90 percent of the total phosphorus transported is sediment-bound. However, only about 50 percent of the total nitrogen is sediment-bound. Models of

TABLE 111
Percent of Nitrogen Forms Transported

Drain	Year	Form of N transported Amm.-N	Nit.-N	Sol Org N	Sed N
Smith-Fry	1975	2.8	35.7	3.2	58.3
	1976	5.8	53.4	3.0	37.8
Dreisbach	1975	4.1	27.2	5.2	63.5
	1976	12.9	36.5	8.1	42.5

TABLE 112
Percent of Phosphorus Forms Transported

Drain	Year	Form of P transported Sol Inorg P	Sol Org P	Sed P
Smith-Fry	1975	2.6	1.8	95.6
	1976	5.9	3.2	90.9
Dreisbach	1975	6.9	2.4	90.7
	1976	19.0	4.2	76.8

P-transport can be based on models of the erosion-sedimentation process. We recommend that models of N-transport should not be based on models of the erosion-sedimentation process only.

5.2.1.3.3 Partitioning of Certain Parameters

The runoff and transported sediment and nutrients were separated into different categories dependent essentially on the size of the runoff event. These categories were: base flow, small events, large events, and snow melt.

Snow melt was a lumped flow event of base flow and small events which occurred during thaw periods. In many instances, the outlet drains were then blocked by ice and snow and the recorded water stages were high. Under these conditions, the snow melt flow reported is our best estimate based on the depth of snow over the drainage area and the amount of rainfall which may have occurred simultaneously with the thaw. Unfortunately, the actual water stage and its uncorrected runoff were reported in some earlier project reports. The data below supersedes that reported earlier.

Base flow can easily be identified from the runoff hydrograph because it is a longtime, steady (depth does not vary with time) flow event. A large event was arbitrarily established as an event which produced more than 2.5 cm (1 inch) of runoff from an entire drainage area. Small events were those flow events which occurred between base flow and large flow events.

The results of partitioning the runoff and transported sediments and nutrients for the Smith-Fry and Dreisbach Drains are given in Tables 113 and 114.

TABLE 113
Partitioning of Runoff, Transported Sediment and Nutrients - Smith-Fry Drain

	Base Flow		Small Events		Large Events		Snow Melt	
Component	1975	1976	1975	1976	1975	1976	1975	1976
	----------------------% transported------------------							
Runoff	17	23	35	14	34	54	14	9
Sediment	3	5	19	6	73	86	5	3
Sol Inorg P	7	13	43	15	37	41	13	31
Sol Org P	14	12	38	14	34	62	14	12
Sed P	1	5	26	6	69	80	4	9
Amm.-N	15	20	34	29	40	36	11	15
Nit.-N	13	13	40	21	27	60	20	6
Sol Org N	18	18	18	20	37	41	27	21
Sed N	1	8	18	9	77	80	4	3

TABLE 114
Partitioning of Runoff, Transported Sediment and Nutrients - Dreisbach Drain

	Base Flow		Small Events		Large Events		Snow Melt	
Component	1975	1976	1975	1976	1975	1976	1975	1976
	----------------------% transported------------------							
Runoff	10	22	37	11	38	56	15	11
Sediment	1	6	14	4	78	84	7	6
Sol Inorg P	6	22	49	5	26	41	19	32
Sol Org P	8	23	42	12	33	52	17	13
Sed P	2	7	32	4	58	78	8	11
Amm.-N	13	20	35	29	28	31	24	20
Nit.-N	8	10	37	7	34	75	21	8
Sol Org N	9	31	27	18	48	36	16	15
Sed N	1	4	23	3	68	83	8	10

The large flow events only occurred a few times during either 1975 or 1976. In 1975 only three storms produced over 2.5 cm of runoff from an entire drainage area and in 1976 only two such storms occurred. Yet these storms accounted for the major sediment and sediment-bound nutrients transported from the two drainages areas. Less than 6 percent of the sediment was transported by base flow and over 70 percent by large flow events.

Conclusion: Transport of sediments and sediment-bound nutrients is strongly associated with large storms which occur only a few times during a year.

With small watersheds, the runoff period is relatively short. The time from the beginning of a storm to the time peak runoff occurs at the outlets of the two drains is between two and three hours. With only a grab sample program it would be very likely that all or parts of the major storm events would have been missed. As a consequence, the sediment and nutrient yields from a small watershed may be grossly underestimated if based on grab sample data. In our case if the large events had been completely missed by a sampling program only about one-third of the actual sediment yield would have been reported. High concentrations in grab samples, if sustained, will still indicate a serious pollution problem. However, an analysis such as we are presenting here would be impossible because of data gaps.

Conclusion: In order to characterize nutrient and sediment loadings from small watersheds, runoff from large storm events must be well-monitored and, with few exceptions, automated sampling is required.

During certain snow melt periods, it was noticed that high loadings of soluble inorganic phosphorus frequently occurred. This may have been caused by a release from decayed vegetative matter at this time. Whatever the exact causes, however, the levels of soluble inorganic phosphorus as well as the other soluble forms of phosphorus and nitrogen were higher during snow melt events than the percentage of runoff during these events would indicate.

Conclusion: During snow melt, the transport of soluble nutrients may be disproportionally high when compared with snow melt runoff.

5.2.1.3.4 Sediment and Nutrients in Runoff

The average concentrations of sediment and nutrients given as a total and also partitioned according to runoff events are given in Tables 115 through 118. Tables 115 and 116 are for the Smith-Fry Drain for 1975 and 1976, respectively, Table 117 and 118 are for the Dreisbach Drain also for these two years.

TABLE 115
Smith-Fry Drain - Sediment and Nutrient Concentrations (1975)

Component	Total	Base Flow	Small Events	Large Events	Snow Melt
	mg/l				
Sediment	730	130	400	1570	260
Sol Inorg P	0.05	0.02	0.06	0.05	0.04
Sol Org P	0.03	0.03	0.04	0.03	0.03
Sed P	1.8	0.11	1.3	3.7	0.51
Amm.-N	0.52	0.46	0.51	0.61	0.41
Nit.-N	6.5	2.1	7.4	5.2	9.3
Sol Org N	0.58	0.61	0.39	0.63	1.1
Sed N	11	0.40	5.6	25	3.1

TABLE 116
Smith-Fry Drain - Sediment and Nutrient Concentrations (1976)

Component	Total	Base Flow	Small Events	Large Events	Snow Melt
	mg/l				
Sediment	520	110	230	830	170
Sol Inorg P	0.05	0.03	0.06	0.04	0.19
Sol Org P	0.03	0.01	0.03	0.03	0.04
Sed P	0.79	0.17	0.35	1.2	0.79
Amm.-N	0.48	0.42	1.0	0.32	0.80
Nit.-N	4.5	2.5	6.8	5.0	3.0
Sol Org N	0.25	0.20	0.36	0.19	0.58
Sed N	3.2	1.1	2.1	4.7	1.1

TABLE 117
Dreisbach Drain - Sediment and Nutrient Concentrations (1975)

Component	Total	Base Flow	Small Events	Large Events	Snow Melt
	mg/l				
Sediment	1430	140	540	2900	670
Sol Inorg P	0.13	0.08	0.17	0.09	0.16
Sol Org P	0.05	0.04	0.05	0.04	0.05
Sed P	1.9	0.38	1.6	2.9	1.0
Amm.-N	0.70	0.91	0.74	0.52	1.1
Nit.-N	4.5	3.6	4.5	4.0	6.3
Sol Org N	0.88	0.79	0.64	1.1	0.94
Sed N	11	1.1	6.8	20	5.9

TABLE 118
Dreisbach Drain - Sediment and Nutrient Concentrations (1976)

Component	Total	Base Flow	Small Events	Large Events	Snow Melt
	mg/l				
Sediment	380	120	140	580	210
Sol Inorg P	0.18	0.18	0.08	0.13	0.52
Sol Org P	0.04	0.04	0.04	0.04	0.05
Sed P	0.72	0.23	0.26	1.0	0.72
Amm.-N	0.84	0.75	2.2	0.47	1.5
Nit.-N	2.4	1.1	1.5	3.2	1.8
Sol Org N	0.52	0.73	0.85	0.33	0.71
Sed N	2.8	0.51	0.76	4.2	2.6

DISCUSSION

These tables reinforce the previous conclusions with regard to the effect of large storm events on sediment and nutrient transport. In addition to amounts, concentrations also increase for large events.

Conclusion: Sediment and sediment-associated nutrient concentrations increase markedly with large storm events.

In 1975, these concentrations (sediment, sed P, sed N) were approximately double that of the average yearly concentrations in the total discharge. Even in 1976, which was a relatively dry year, these concentrations were approximately 50 percent higher than the average yearly concentrations. However, the concentrations of the soluble forms of nitrogen and phosphorus for the large events were in general about equal to the average yearly concentrations in the total discharge. This was probably due to dilution by large runoff volumes. On the other hand, the concentrations of soluble forms in snow melt were in general higher than the average yearly concentrations in the total discharge.

It would be difficult just by looking at these average concentrations to judge whether the streams in the Black Creek Watershed are meeting the "fishable and swimmable" criteria set forth in PL 92-500, the clean water bill. During critical low flow periods which normally occur in late summer and fall, the flow remaining in the streams often collects into shallow, stagnating pools. If sunlight is available, considerable blue-green algal growth may occur. What through-flow occurs is sometimes augmented by septic tank discharge which should actually be classified and treated as point source pollution. Septic tank discharge may keep the streams in the watershed from drying up completely, but on the other hand, it provides the nitrogen and phosphorus necessary for algal growth.

It is difficult to compare our records with those for the Maumee River. In 1976, the sediment loss from the Black Creek Watershed was about the same as the longterm average from the Maumee River as measured at Waterville, Ohio. In 1975, however, the sediment loss from the Black Creek Watershed was over four times the longterm average recorded at the station in Waterville. The total phosphorus concentration in the Maumee River at New Haven which is just above the entrance of Black Creek into the Maumee River as measured by the Water Pollution Control Plant of Fort Wayne averaged about 0.45 mg/l for 1975-76. Their average measured sediment concentration for these two years was around 80 mg/l. Our measurement of total phosphorus concentrations at the State Route 101 bridge across the Maumee River and just below the entrance of Black Creek into the river were 0.48 mg/l and 0.43 mg/l for 1975 and 1976, respectively. Our average measured sediment concentrations were 240 mg/l and 140 mg/l for these two years. All of the water samples, those collected by the Water Pollution Control Plant of Ft. Wayne and by us, were grab samples and the concentrations were not flow weighted. We collected more samples particularly during storm events. This could account for much of the difference between the values for sediment concentrations.

The total phosphorus concentrations agree closely. Both sets of data also indicate that total phosphorus concentrations in the Maumee River are not correlated closely to sediment concentrations. Our data for the Maumee River show that 21 percent of the total phosphorus concentration in 1975 and 42 percent of the total phosphorus concentration in 1976 was soluble phosphorus. The total phosphorus concentrations in the Maumee River seem to be greatly influenced by soluble phosphorus; on the other hand, the total phosphorus concentrations in the Black Creek Watershed are greatly influenced by sediment-bound phosphorus.

The average suspended sediment concentration at Waterville, Ohio, near the entrance of the Maumee River into Lake Erie is approximately 200 mg/l. This corresponds to the sediment concentrations reported above and indicates that if comparisons with our data can be made they should be with our base flow and some part of our small flow events and certainly not with either our total flow or large flow event categories. If we did this, then the concentrations of total phosphorus and suspended sediments seem to be in rough agreement.

Conclusion: Average concentrations of sediments and nutrients discharged from the Maumee River are in line with measurable concentrations in the Maumee River.

This conclusion seems to skirt the issue of the source of the nutrients in the Maumee River. However, there is a scarcity of data, especially of data which were gathered and analyzed the same way, for valid comparisons to be made. Certainly, we do not wish to give the impression that reductions of nutrient loadings from agricultural watersheds into the Maumee River are not desirable. On the other hand, the relatively large concentrations of soluble phosphorus in the Maumee River would indicate that industries and municipalities still have a job to do also.

5.2.1.3.5 Runoff,Sediment,Nutrient Sources

The probable sources of runoff and transported sediment and nutrients in the Smith-Fry and Dreisbach Drain for 1975 and 1976 are given in Tables 119 through 122. The waste treatment facility for almost all non-Amish homes in the watershed is a septic tank which is discharged directly with a tile drain or a stream. The sewage column reflects the contribution of outfalls for septic tanks. Calculations were made by assuming the discharge from each home to be 100 gallons per day. The column for rain shows those chemical components which were measured in rainfall as a percentage of the total amount which was discharged for that particular year. It does not represent the proportion of the soluble forms which was contributed by rainfall, but it merely indicates that rainfall is also a potential source for these phosphorus or nitrogen forms. The contribution of soluble inorganic phosphorus by rainfall would be included in the column for land, and the contribution of ammonium or nitrate-nitrogen by rainfall might be included under the tiles, interflow or land columns.

Conclusion: Losses of soluble inorganic phosphorus, ammonium and nitrate-nitrogen from the watershed are partially due to the input of these chemical forms by precipitations.

The land surface was the major source of the sediment and nutrients which were transported in the Smith-Fry and Dreisbach Drains during 1975. Over 90 percent of the sediment and sediment-bound nutrients originated from the land surface during that year. This also held true for the Smith-Fry Drain in 1976. However, in the Dreisbach Drain during 1976, sewage outflow which constituted only 3 percent of the runoff contained substantial percentages of the soluble nutrients as well as some sediment-

TABLE 119
Sources of Runoff, Transported Sediment and Nutrients - Smith-Fry Drain (1975)

Component	Tiles	Interflow	Sewage	Land	Rain*
	% transported				
Runoff	15	17	0.3	64	
Sediment	1.3	--	0.2	97	
Sol Inorg P	4	5	27	64	(115)
Sol Org P	8	9	5	78	
Sed P	0.6	--	6	93	
Amm.-N	9	10	5	76	(340)
Nit.-N	25	28	1.1	46	(35)
Sol Org N	9	10	--	81	
Sed N	0.2	--	0.4	99	

* Percentage of soluble nutrient as measured in the storm which could have been supplied by rainfall.

TABLE 120
Sources of Runoff, Transported Sediment and Nutrients - Smith-Fry Drain (1976)

Component	Tiles	Interflow	Sewage	Land	Rain*
	% transported				
Runoff	8	18	0.7	73	
Sediment	1.4	--	0.6	98	
Sol Inorg P	2	5	57	36	(150)
Sol Org P	15	16	15	62	
Sed P	0.4	--	7	93	
Amm.-N	5	12	12	71	(540)
Nit.-N	18	43	4	35	(74)
Sol Org N	11	13	--	76	
Sed N	0.3	--	3	97	

* Percentage of soluble nutrients as measured in the stream which could have been supplied by rainfall.

bound nutrients.

Relatively high amounts of soluble inorganic phosphorus originated from septic tank outfalls in all cases as indicated by percentage figures. And relative high amounts of nitrate-nitrogen were associated with either tile drainage or interflow into the streams.

The contribution of the discharge from subsurface drainage systems to sediment yield was not large and certainly not at all approaching the amounts reported elsewhere in the Maumee Basin (7). Based on the sampling of discharge from select tile outlets it was estimated that subsurface drains accounted for only one to two percent of the total sediment yield from the Black Creek Watershed.

Conclusion: Most of the sediment and sediment-bound nutrients originate in runoff from the land surface. The discharge of ammonium is also largely associated with runoff from the land surface. However, the discharge from septic tank outlets contributes substantial amounts of soluble inorganic phosphorus into the streams in the watershed.

5.2.1.3.6 Average Yearly Concentrations

TABLE 121
Sources of Runoff, Transported Sediment and Nutrients - Dreisbach Drain (1975)

Component	Tiles	Interflow	Sewage	Land	Rain*
	% transported				
Runoff	23	8	1.2	68	
Sediment	1.1	--	0.4	98	
Sol Inorg P	7	2.4	37	54	(46)
Sol Org P	15	5	14	66	
Sed P	0.9	--	5	94	
Amm.-N	7	2.4	13	78	(280)
Nit.-N	25	9	6	60	(56)
Sol Org N	13	5	--	82	
Sed N	0.8	--	1.1	98	

* Percentage of soluble nutrient as measured in the stream which could have been supplied by rainfall.

TABLE 122
Sources of Runoff, Transported Sediment and Nutrients - Dreisbach Drain (1976)

Component	Tiles	Interflow	Sewage	Land	Rain*
	% transported				
Runoff	12	13	3	72	
Sediment	2	--	7	91	
Sol Inorg P	3	3	71	23	(54)
Sol Org P	10	11	44	35	
Sed P	1	--	35	64	
Amm.-N	3	4	28	65	(380)
Nit.-N	24	26	30	20	
Sol Org N	11	12	--	77	
Sed N	2	--	16	82	

* Percentage of soluble nutrient as measured in the stream which could have been supplied by rainfall.

The average yearly sediment and nutrient concentrations in the runoff at the outlets of the Smith-Fry and Dreisbach Drains are given in Tables

123 and 124, respectively.

TABLE 123

Yearly Concentrations, Transported Sediment & Nutrients-Smith-Fry Drain (75-76)

Component	Stream	Tiles	Interflow	Sewage	Land	Rain
	mg/l					
Sediment	630	60	--	470	1060	
Sol Inorg P	0.05	0.01	0.01	4.2	0.05	0.014
Sol Org P	0.03	0.02	0.02	0.57	0.03	
Sed P	1.3	0.04	--	8.4	2.1	
Amm.-N	0.50	0.31	0.31	8.0	0.59	0.46
Nit.-N	5.5	11	11	24	5.9	.59
Sol Org N	0.42	0.35	0.35	--	1.0	
Sed N	7.1	0.12	--	15	13	

TABLE 124

Yearly Concentrations, Transported Sediment & Nutrients-Dreisbach Drain (75-76)

Component	Stream	Tiles	Interflow	Sewage	Land	Rain
	mg/l					
Sediment	910	70	--	470	1570	
Sol Inorg P	0.16	0.04	0.01	4.2	0.14	0.014
Sol Org P	0.05	0.03	0.02	0.57	0.04	
Sed P	1.3	0.07	--	8.4	1.7	
Amm.-N	0.77	0.22	0.22	8.0	0.97	0.46
Nit.-N	3.5	4.9	4.9	24	3.6	0.59
Sol Org N	0.70	0.48	0.48	--	0.75	
Sed N	6.9	0.36	--	15	10	

The concentrations in the column for stream are the average flow-weighted concentrations from the sources: tiles, interflow, sewerage, and runoff. The concentrations of soluble nutrient forms in the column for rain are given as reference values only.

The yearly concentrations are averages of the concentrations for a relatively wet and a relatively dry year and so might well be good estimates of the longtime yearly concentrations in the Smith-Fry and Dreisbach Drains. As such they tend to reinforce the conclusion that the average concentrations seem to be in line with the measurement of similar concentrations in the Maumee River.

5.2.1.3.7 Average Nutrients on Sediments

The average yearly concentrations of total nitrogen and phosphorus in suspended sediments from the Black Creek Watershed are shown in Table 125. Also shown are these concentrations with respect to relatively undisturbed soils in the watershed.

TABLE 125
Yearly Concentrations of Total N and P Attached to Sediment (1975-76)

Soil and Sediment	Total N	Total P
	g/l	
Watershed Soils	1760	680
Sediment:		
Stream	8900	1800
Tile drains	3600	950
Septic tanks	24000	19000
Surface runoff	8800	1600

The average yearly concentrations of the nutrients attached to sediments in Black Creek, in the outflow from tile drainage underlying portions of the watershed, in the effluent from septic tanks into the watershed streams, and from surface runoff can be compared to these concentrations which are attached to relatively undisturbed soils in the watershed.

Conclusion: Sediments in runoff are nutrient enriched. The least enrichment occurs from subsurface drainage systems and the most from septic tank outfalls. The sediments in Black Creek have an enrichment factor of about three as compared to the uneroded soils in the watershed.

5.2.1.3.8 Estimate of Added Nutrients Lost

The estimation of nutrients which were added as commercial fertilizers or manures lost from the Black Creek Watershed is a tenuous undertaking but certainly one which should be addressed. Estimates of the application rates for fertilizers and manures were based on a questionnaire (8).

A nitrogen balance for the entire watershed subdivided between Amish and non-Amish farms is shown in Tables 126 and 127. The amount of nitrogen applied as commercial fertilizer and manure and fixed by legumes was regarded as the same for both 1975 and 1976. We assumed that mineralization of nitrogen was balanced by that which was fixed in the soil mass. The input of nitrogen caused by that portion of the precipitation which infiltrated into the soil was added to the subtotal for both years. The total applied or fixed nitrogen was then estimated as 329,500 kg for 1975 and 316,500 in 1976.

The applied or fixed nitrogen lost from the watershed was the measured amount of soluble inorganic nitrogen discharged from the watershed minus the contribution from septic tank outfalls and that portion of the percipitation which occurred as runoff. The loss of applied or fixed nitrogen from the Black Creek Watershed was then estimated as 66,000 kg for 1975 and 10,700 kg for 1976.

If we assume that the same proportion of the applied or fixed nitrogen was lost, then 20 percent of the nitrogen applied as commercial fertilizer and manure was lost in 1975, a very wet year, and 3 percent was lost in 1976, a relatively dry year. The loss of soluble inorganic phosphorus ori-

TABLE 126
Estimate of Annual Applied Fixed Nitrogen

Nitrogen Source	Amish	Non-Amish	Total
	kg		
Commercial fertilizer or manure:			
Corn	12,200	153,200	165,400
Soybeans	-	5,700	5,700
Small grain	5,400	23,400	28,800
Hay and pasture	13,800	3,000	16,800
Fixation:			
Soybeans	-	57,900	57,900
Forage legumes	11,000	1,200	12,200
Total	42,400	244,400	286,800

TABLE 127
Estimate of Percent Applied and Fixed Nitrogen Lost (1975-76)

Nitrogen Input or Loss	1975	1976
	kg	
Applied and fixed nitrogen inputs	286,800	286,800
Input due to infiltrated precipitation	42,700	29,700
Total nitrogen input	329,500	316,500
Total nitrogen loss (measured)	87,400	22,700
Loss due to precipitation runoff	14,100	5,800
Loss due to septic tank discharge	7,300	6,200
Applied and fixed nitrogen loss	66,000	10,700
Percent applied and fixed nitrogen lost	20%	3%

ginating as commercial fertilizer or manure was estimated to average about 0.3 percent per year for 1975 and 1976.

The estimated loss of soluble inorganic nitrogen from commercial fertilizers or manures is in line with estimated losses from other areas with similar application rates. The loss of added phosphorus in a soluble form is relatively low and suggests that most of it was immediately tied up in the soil complex. However, more phosphorus could be expected to be lost through the erosion process. We did not attempt to evaluate this because of our imprecise knowledge of where erosion was occurring in relation to the areas which received phosphorus fertilization.

The total nitrogen loss per hectare from the Smith-Fry Drain was only about 20 percent higher than from the Dreisbach Drain (see Table 109). However, the percentage of the drainage area of the Smith-Fry Drain in row crops was about double that for the Dreisbach Drain. It is probably reasonable to expect that most of this difference was due to the increased usage of commercial fertilizers on the lands contributing runoff to the

Smith-Fry Drain. Improved fertilizer management techniques may still decrease the amounts of soluble inorganic nitrogen reaching the streams in the Black Creek Watershed, but the level to which it can be reduced is certainly bounded and the effect of improved techniques may not be all that noticeable in loadings from the watershed into the Maumee River.

5.2.1.3.9 Another Factor -- The Farming Community

The Black Creek Watershed is somewhat atypical of similar sized areas in the Maumee Basin in relation to its comparatively larger settlement of Amish farmers. Most of them have farms on the glacial till soils which occur in the northern part of the watershed. The land farmed by the Amish in the drainage areas of the Smith-Fry and Dreisbach Drains is roughly in proportion to the percentages of glacial till soils in these two areas (see Table 108). Some aspects of their farming operations which would have a beneficial effect on the level of non-point source pollution from agricultural lands were (1) a rotational type agriculture which included pasture and small grains and (2) limited usage of commercial fertilizers. Some negative factors were (1) fall plowing of erosive soils, (2) overgrazing of pastures, (3) low crop yields which would increase the erosion potential from their farms, and (4) use of streams for watering livestock.

The lands which are farmed by the Amish are in general mostly rolling. Practices for reducing nonpoint source pollution are particularly effective on these lands. As reported elsewhere in this volume, good cooperation was generated with the Amish community and many beneficial practices including parallel tile outlet terraces have been installed on their farms.

During the period of record reported on here, however, and in particular for 1975, very few of these practices had been installed. Based on our records and also on observation of lands on which severe erosion was occurring, we have concluded that the 19th century farming techniques as used by the Amish did not seem to improve the water quality in streams from that area of the Black Creek watershed in which they reside. On the other hand, we expected the greatest reduction of nonpoint source pollution from that area in the future. We have in the Black Creek Watershed a unique opportunity to study "old and modern" agriculture and their relative effects on the quality of our water resources. Further analyses will be made based on our water sampling program and also on our modeling effort as reported in Section 0.0.

5.2.1.3.10 Effect of Agricultural NPS Pollution

The actual impact of sediment, phosphorus and nitrogen discharged from the Black Creek Watershed and other agricultural watersheds in the Maumee Basin on the eutrophication process in the Maumee River and Lake Erie is speculative and needs further study. Phosphorus is largely sediment-bound and would have to be released in order to enter into the nutrient cycle of the algal biomass. In a study reported elsewhere in this report only about 15 percent of the phosphorus which was bound to sediments could become available for algae growth. This was for a laboratory situation where light was not limiting as it would in fact be in a lake environment. Regarding nitrogen, a large percentage of the total nitrogen discharged occurs in the late winter and spring months during high flows. Just how much would remain and be available later in the year for usage by the algal biomass is also largely unknown at this time.

Nonpoint source pollution from the Black Creek Watershed occurs primarily from large storm events. These large storm events usually occur during the spring and early summer months. Also the chances are that the Maumee River is at a moderately high stage during the period when the large storm event occurs. On the other hand, the input of point source pollution is most critical in the Maumee River during its low flow periods. While there may be some residual chemicals remaining from high flow periods, the effect of agricultural nonpoint source pollution by-and-large should not be evaluated using low flow criteria as is characteristic for point source pollution.

Conclusion: The effects of agricultural nonpoint source pollution and point source pollution on our water resources are sufficiently different that direct comparisons between them can not be made and separate objectives for their evaluation and control are in order.

5.2.1.4 SUMMARY

An analysis of rainfall, runoff, and transported nutrients from the Black Creek Watershed for 1975 and 1976 was made. Rainfall was about 20 percent over normal in 1975 and, to the other extreme, about 20 percent less than normal in 1976. We were fortunate from a data collection standpoint to have experienced these extreme rainfall conditions since there is no guarantee that a much longer period of record would have produced these rather extreme weather conditions. Future years of record will be used to verify our conclusions.

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5.3 LOCAL VARIATIONS IN WATER QUALITY

Water quality in the Black Creek watershed varies strikingly over space and time. Spatial variation results from differing typographies, soil types, land use, and channel characteristics. Temporal variation includes changes due to the seasons with added variation due to changing flow regimes. The following discussion illustrates several patterns of variation.

5.3.1 Water Quality During a Drought

The Black Creek watershed experienced a prolonged dry period in summer 1976 and, thus, provided an excellent opportunity to determine water quality characteristics at base flow. During this period rainfall events were generally less than one inch and were quickly absorbed by dry soil resulting in very little or no surface runoff. Most suspended solids and nutrients carried in Black Creek were from within streams, drain tiles, and domestic sewage sources. Furthermore, by late summer most of the streams in the watershed were reduced to isolated pools with no surface flow.

Because of the low flow conditions on the Black Creek watershed during July, August, and September 1976 it was possible to divide the watershed into several distinct units (Figure 37). The lower reaches of Black Creek had a base flow maintained by groundwater all summer. Estimated flow rates during these base flow conditions ranged from 0.0005 to 0.0040 cubic meters/sec. Most of the water for this flow originates at two distinct locations; Gorrell Drain at Notestine Road and about 150 m downstream from station 131 (east of Bull Rapids road on Black Creek). Water samples of this outflow reflect lower phosphorus, ammonia, and turbidity levels than found at downstream stations (Table 128). Data for Table 128 were collected on August 24 and 25 after a period of at least one week without flows from any tributary drain or from the upper reaches of Black Creek. Since there was no surface runoff or upstream channel flow, the changes in water chemistry indicated by Table 128 result from the accumulation of materials from the stream channel and riparian environment of Black Creek. A hog watering facility a short distance above station 132 may have been responsible for some of the changes in concentrations of some nutrients. Unfortunately, we did not have any sample stations between the groundwater source and the hog lot.

Two sources of pollutants in the lower section of Black Creek were tile lines near stations 140 and 154 which carried domestic sewage effluent. No significant shifts in water chemistry could be detected at these locations, suggesting that these sources were of little consequence in affecting water chemistry at base flow conditions.

Immediately following the few rainfall events of summer 1976 Dreisbach and Richelderfer Drains experienced increased runoff rates while other tri-

TABLE 128
Characteristics, Groundwater, Channel Flows, Black Creek

Parameter(c)	Groundwater	Stagnant Stream Water(a)
Alkalinity	267	268.7 +- 6.35
Conductivity	702	783.7 +- 35.01
Dissolved Solids	512	571.3 +- 25.00
Hardness	357	358.3 +- 3.51
Turbidity	27	58.0 +- 4.00(b)
Total Phosphorus	0.047	0.64 +- 0.02(b)
Soluble Orthophosphate	0.003	0.04 +- 0.008(b)
Nitrate	0.01	0.01
Nitrite	0.01	0.01
Ammonia	0.01	0.087 +- 0.005(b)
Organic Nitrogen	0.29	0.313 +- 0.095
Total Residue (Suspended Solids)	532	578.7 22.7
Sulfate	88.1	88.8 1.15

(a) Stations 132-134, Mean +- standard deviation
(b) Groundwater and channel flow concentrations significantly different at $p<0.05$
(c) mg/l except turbidity in Jackson Turbidity Units

butaries were little affected by the rains. These intermittent flows identify a second major area of the watershed: areas with very low flow or intermittent flow through most of the summer but with an occasional spate originating in Harlan (Figure 37). We do not have any regular sampling stations on Richelderfer Drain near Harlan but a series of stations on Dreisbach Drain yields interesting results. Virtually all water chemistry parameters increase sharply as the stream passes Harlan (Stations 115 and 116). As the stream continues south beyond Harlan all parameters decline

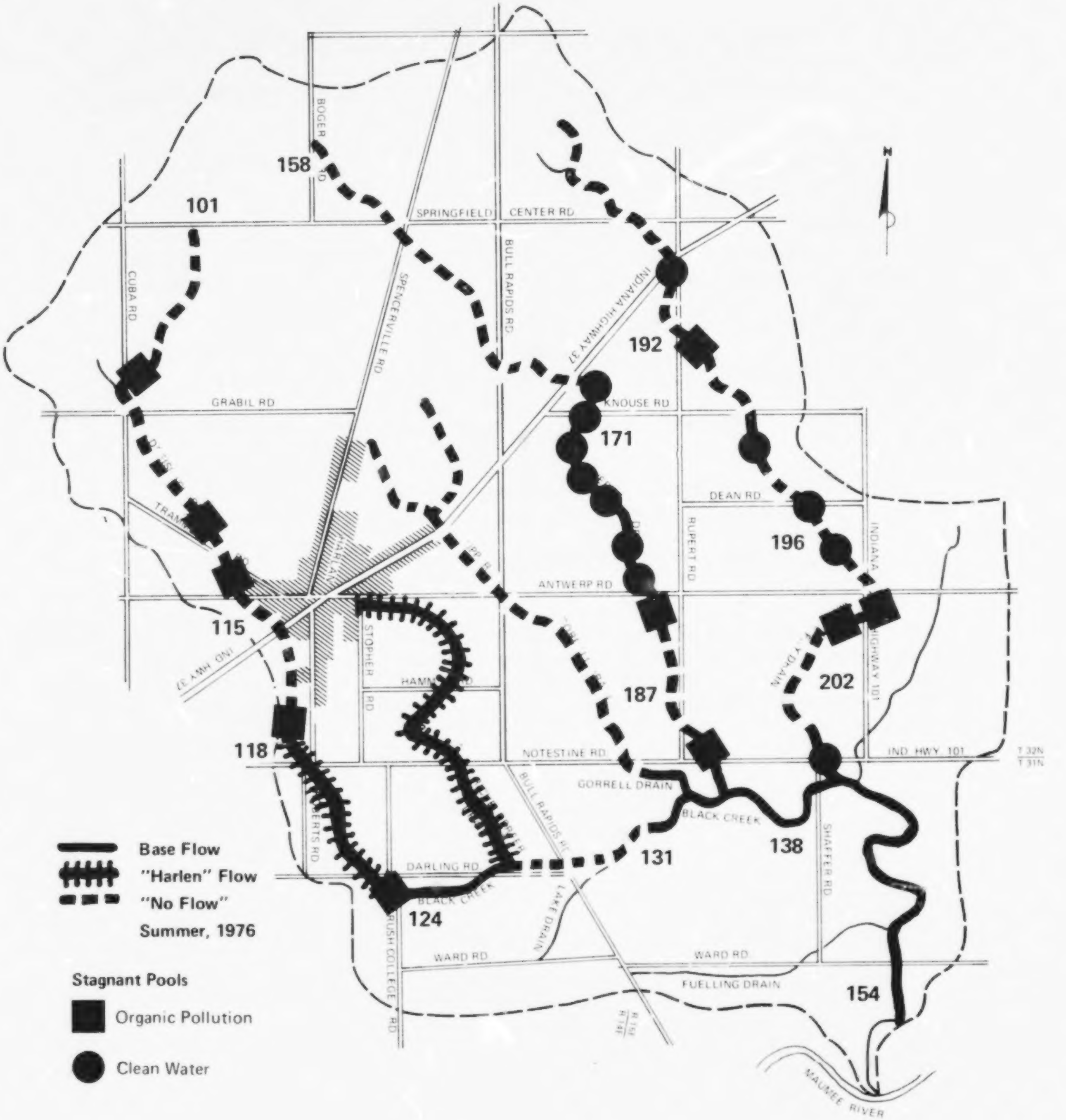
158
101
192
171
196
115
187
202
118
131
138
124
154
BOGER RD
SPRINGFIELD CENTER RD
CUBA RD
SPENCERVILLE RD
BULL RAPIDS RD
INDIANA HIGHWAY 37
GRABIL RD
KNOUSE RD
DEAN RD
RUPERT RD
INDIANA HIGHWAY 101
ANTWERP RD
HARLAN
STOPHER RD
HAMM RD
IND HWY 37
NOTESTINE RD
IND HWY 101
T 32N
T 31N
GORRELL DRAIN
BLACK CREEK
SHAFFER RD
DARLING RD
BULL RAPIDS RD
LAKE DRAIN
RUSH COLLEGE RD
WARD RD
WARD RD
FUELLING DRAIN
MAUMEE RIVER
N
Base Flow
"Harlen" Flow
"No Flow"
Summer, 1976
Stagnant Pools
Organic Pollution
Clean Water

Figure 37 Flow Regimes in Watershed

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and reach levels similar to those above Harlan. This generally happens at or slightly below station 118 about 1 km south of Harlan. This seems to be a result of settling out of organic matter between stations 115 and 118. Apparently, this particulate matter cannot be metabolized by the stream ecosystem during low flow periods. It accumulates in anaerobic sediments and is later washed downstream during rainfall events (see discussion of microbiological sampling). A population of fish is able to persist at station 118 but very few persist above that sample station.

The dynamics of nutrients in this section of stream are less clear. Perhaps the decline in nutrients is due to incorporation into algal biomass, which settles to the bottom. It is then flushed out with other organic matter during runoff events.

Observations of Richelderfer Drain in late September and October indicate that channel flow from Harlan is considerably more turbid than that in the main Black Creek channel.

The third major situation in the watershed existed upstream of Harlan on the Dreisbach and throughout Wertz and Smith-Fry Drains. Generally, flow conditions in these areas were very low or stagnant. Upper Dreisbach (above station 113) remained dry through much of the summer (Table 129). Some flow occurred in Smith-Fry Drain in late June and July and flow rates in Wertz Drain were lower and more intermittent. Most areas along the tributaries were reduced to standing pools many of which dried up completely by the end of the summer. This resulted in progressive concentration of fishes and ultimately death for many as habitat deterioration made them especially susceptible to raccoon and other predators. The most severe condition occurred in early September when the isolated pools could be classed into two groups. Many pools were maintained by septic tile flows which commonly contained significant amounts of organic effluents (Figure 37). Pools in areas not receiving such effluent maintained relatively better water quality.

TABLE 129
Stations with Water - Dreisbach Drain

		No. of Stations Without Water On					
Stream Segment	Total Number of Stations	June 10	June 29	July 13	July 26	Aug 9	Aug 24
Upper Segment (Springfield Center to Antwerp Roads	11	2	4	8	9	9	10
Lower Segment	9	0	0	0	1	0	4

5.3.2 Effects of Channel Morphology

The general program of water sampling in the Black Creek Study involves routine and often automated sampling of water at a number of locations around the watershed. This sampling protocol has been supplemented with detailed surveys of water quality throughout the watershed. Initially, we sampled the segment of Wertz Drain between Knouse and Antwerp Roads. Between those two roads there is about 1800 m of stream channel, of which about 550 m meanders through a small patch of mixed forest. Tree dominants in the forest include oaks (Quercus), hickories (Carya), maples (Acer), and beech (Fagus). Within the 1800 m section of stream, 12 sample stations (later expanded to 16) were established. Three upstream stations (#10-12) are in a region of grass waterway bordered by agricultural land. Stations 6-9 are within the main woodlot area and 4-5 are in a small extension of forest bordering the stream. The remaining stations (1-3) are in a region of grass waterway bordered by agricultural land. Station 2 is on a bend in the stream in an area with several large cottonwoods (Populus). A steep badly eroded bank is located just above station 2. Inside the forest no grass stabilizes the bank, and the stream forms a complex of pools and riffles meandering widely through the forest. Just below station 7 a badly eroded tile drain enters the main channel.

Since February 1975 we have collected water samples regularly from the Wertz Drain. Briefly our results demonstrate that sediment loads decline as the water flows through the area. Furthermore, very soon after the stream leaves the forest, sediment load increases and stabilizes near a level characteristic of the Wertz Drain above the forest.

Variations within the agricultural and forested section of the stream are also of interest. For example, a typical increase at station 5 is apparently due to the nearby entry of a large drainage tile from adjacent fields. Considerable erosion is evident at that point. Note that even the presence of a small finger of forest extending south from station 5 results in a decline of sediment load to station 3. As the stream continues south to station 2 sediment loads increase significantly until they approach levels above those in the forest.

A series of t-tests to determine the significance of variation in sediment loads shows that stations above the forest are not significantly different in suspended solid content from the lower two stations. Stations 10-12, and 1-2 are significantly higher than stations at the lower end of the forest (stations 4 and 6) indicating that the forest acts as an effective sediment trap in reducing suspended solids by about 28%.

At very high stream flows, the forest apparently has little impact on reducing sediment loads. We obtained water samples shortly after a very heavy rain (about 10 cm in 2 hours) in 20 May 1975. From station 12 to 1 there was a gradual increase in suspended solids through the Wertz Drain Study Area. Furthermore, the increased load of sediment seems to be a general phenomenon as the load increased from the headwaters of the streams to near the junction of Black Creek and the Maumee River. These results suggest that the forest acts as a very efficient trap for removing suspended solids during most flow rates (>95%, Beasley, pers. comm.) but at very high flow rates the forest has no value as a sediment trap.

Initially, we were not able to determine the factors responsible for declining sediment loads. However, we are now convinced that sediment reductions are due to the physical processes obtaining in the forested section of the watershed. From unit stream power theory sediment reductions on the order of 25% are expected in a meandering pool-and-riffle channel like that in Wertz Woods and observed sediment declines were 28%. The roughness coefficient (n) is the likely factor responsible for the decreased sediment loads since the slopes (S) are lower (.25) above and below the woodlot than in the woodlot (.40).

5.3.3 Variations in Water Quality

From an initial sampling base of 12 stations on a small section of the Wertz Drain we have expanded to an intensive series of 120 sample stations throughout the Black Creek watershed (Figure 0). These stations were selected to allow intensive sampling on four major areas of the watershed.

1. Dreisbach Drain. Since the initiation of the Black Creek Sediment Control Project, Dreisbach Drain has been the subject of intense efforts to improve agricultural and conservation practices. A series of 20 channel stations between Springfield Center and Brush College Roads has been established to monitor the impact of changes in agricultural and conservation practices on water quality.

2. Wertz Drain. Our original sampling included 12 stations between Knouse and Antwerp Roads. The number of stations in that reach has been expanded to 16 and an additional 18 stations have been located in the remainder of the Wertz Drain between Boger Road and Black Creek. This expansion is designed to clarify the changes in stream quality resulting from several planned conservation activities initiated in the summer of 1976.

3. Smith-Fry Drain. Little or no conservation planning work had been initiated on the Smith-Fry Drain by summer 1976. As a result, water quality in this channel may reflect that of other Black Creek tributaries before initiation of the Black Creek Sediment Control Project. A total of 23 channel stations is located along the Smith-Fry Drain.

4. Black Creek. Thirty-two stations have been located along the Black Creek channel between Brush College Road and the Maumee River. The deeper waters and increasing flow volumes of the Black Creek channel will help to clarify the dynamics of sediment and nutrient movements in larger streams.

In addition to these stations a number of other sites have been selected to measure such areas as tile outflows from fields with and without parallel tile outlet terrace systems. The sample sites for this expanded effort have been selected to sample areas of different stream morphology, land use, vegetation cover, and other factors.

As demonstrated by earlier studies of the Wertz Woods area, local variation in streamside vegetation, channel morphology, and land use affect water quality characteristics. Water quality varies strikingly within and between waterways within the Black Creek watershed (Table 130). At present all of the cause and effect relationships which account for this variation are not known.

However, some small scale variation can be accounted for. At station 189 at the lower end of Wertz Drain suspended solids loads increased by about 200/mg/l as a result of domestic ducks feeding in the channel at that location.

In the case of phosphorus spikes are especially high at Harlan where

TABLE 130
Water Quality Characteristics - Major Segments

	Stream Segment				Index
Parameter	Dreisbach	Wertz	Smith-Fry	Black Creek	Value*
Phosphorus					
Total Phosphorus	High	Low	Very Low	I (D)**	0.70
Soluble Orthophosphate	High	Very Low	Very Low	I (D)	0.15
Nitrogen					
Nitrate	Very High	Very High	High	I	0.01
Nitrite	Very High	I	High	I	0.03
Ammonia	Very High	Low	Low	I (D)	0.40
Organic Nitrogen	Very High	I	Low	I (D)	0.50
Other Parameters					
Turbidity	I	Low	Low	I	50
Total Residue (Susp. Solids)	High	Low	Low	I	600
Alkalinity	High	High	I	I (D)	140
Hardness	High	I	High	I	220
Conductivity	High	Low	Low	I (D)	700
Dissolved Solids	High	Low	Low	I (D)	500
Sulfate	High	Low	Low	I	30

** I=Index Value
(D) = Decreasing trend through this segment of the watershed.
* Concentration in water in mg/l except for turbidity which is measured in Jackson Turbidity Units.

concentrations are up to 10 and 100 times higher than the index value for total phosphorus and soluble orthophosphate, respectively.

We are conducting analysis and continuing monitoring efforts to demonstrate how specific land use and channel characteristics affect water quality parameters. However, one point is clear. Variation in sediment and nutrient loads over short stream distances may be striking for a large complex of reasons. Clearly, when sediment and nutrient loads may vary by orders of magnitude over relatively short distances, it is important to use caution in the selection of sampling localities for monitoring of water quality. This is obviously true where point-source inputs are present. However, evidence that channel structure and other factors have effects on transport and deposition suggests that care should be taken in selection of monitoring sites even where non-point sources predominate. Ideally, a set of recommendations should be developed to aid researchers in selection of monitoring sites. At the present time it is only possible to suggest that caution be exercised. Concentration and loading estimates will be affected

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by carelessness in site selection.

5.3.4 Effects of Construction Activities

Short term effects of construction may cause significant changes in water quality. Activities of heavy equipment in pulling channel banks and bottom-dipping commonly created visible changes in water quality. This is especially true of suspended solids which increase markedly downstream from construction areas.

5.3.5 Effects of Conservation Practices

As discussed in Section 0.0.6, channel modification activities on the Wertz Bank upstream from Wertz Woods on Wertz Drain has had a significant affect on downstream channel characteristics. Erosion of unstable bank and channel bottom after construction in Wertz Branch yielded large amounts of sediment. As this sediment moved downstream it was deposited in downstream areas (especially Wertz Woods). This deposition has all but obliterated many of the pool and riffle areas. Implementation of this conservation practice has over the short term increased sediment loads and affected down stream biotic communities by destroying several habitat types (pools and riffles) and by creating very unstable substrates (shifting sand and silt bottoms) in a number of downstream reaches.

Another example of a conservation practice affecting water quality comes from the desilting basin constructed on the main Black Creek Channel below Station 15. While large amounts of sand have been deposited in this basin since its construction our data show that during low flows total residue, total phosphorus and turbidity are significantly higher at the outlet than at the entry of the basin (Table 131). Total residue is increased by 8% while total phosphorus and turbidity increase by 58% and 41% respectively. The ratio of total residue to turbidity declines from station 145 to 146. This ratio can be viewed as coefficient of fineness of suspended materials where a decreasing value indicates increased proportion of fine particles in suspension. The reason for this cannot be definitely established but may be due to such factors as increased turbidity due to wind fetch or feeding activities of fish although feeding activities of fish seems unlikely as ammonia levels do not increase in the desilting basin. Another possibility is that algal populations have increased. Without knowledge of carbon fractions, it is difficult to distinguish that possibility from the more likely effect of wind fetch. The desilting basin seems to be functioning as a turbid pond.

The accumulation of sand size particles in the desilting basin suggest that bed load is reduced by deposition in the basin but evidence described above shows that fine particle material increases. The rapid rate of filling the basin with sands shows that regular maintenance activities will be required to maintain an efficient operation. Such costly, repetitive maintenance combined with the high sediment movement associated with construction and increased fine particle concentrations associated with the basin suggest that this may not be a sound practice for improvements in water quality.